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RELATIVE RESISTANCE OF VARIOUS CONIFERS TO INJECTION WITH CREOSOTE.

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PURPOSE OF THE EXPERIMENTS.

It is very difficult and sometimes apparently impossible to secure uniform treatments of wood with preservatives. If, for example, an average treatment is given of 10 pounds of creosote per cubic foot, some pieces of wood in a charge will receive twice the average amount, while others will receive less than one-half of it. Efficient use of the preservative obviously requires that each timber receive its full portion and no more. One essential condition for securing uniformity of treatment is that all pieces in any one charge shall present equal resistance to injection. This requires that the wood be graded in accordance with its ease of treatment, and the experiments here described were made to investigate this subject. To obtain a logical basis for such classification it was necessary to study the relation between the structure of wood and the manner in which it receives treatments. This study was carried out at the Forest Products Laboratory maintained in cooperation with the University of Wisconsin, at Madison, Wis. The present publication is confined to coniferous woods.

STRUCTURE OF THE CONIFERS.

The woods of cone-bearing trees, or conifers, have certain similarities of structure which distinguish them from the woods of broad-leaved trees. In commerce the terms "softwoods" and "hardwoods" are applied respectively to these two classes of wood. The following description of wood structure applies only to the conifers.

Note.—The purpose of this bulletin is to show how woods should be graded in order that they may give uniform results when subjected to treatment with preservatives; it is intended for those interested in wood preservation.

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GROSS STRUCTURE.

On any cross section of a log a zone of light-colored wood next to the bark may usually be distinguished from the inner portion of the log. This outside zone is the sapwood; the inner darker portion is the heartwood. In the sapwood many of the cells are used for conduction and storage of materials necessary in the life processes of the tree; the outer layer of cells, called the cambium, forms the growing part. The darker color of the heartwood is due to the infiltration of chemical substances into the cell walls, but the cavities of the cells generally are not filled up, as is sometimes believed. Sapwood varies, even within the same tree, in its relative width and in the number of rings which it contains; the same year's growth may be sapwood in

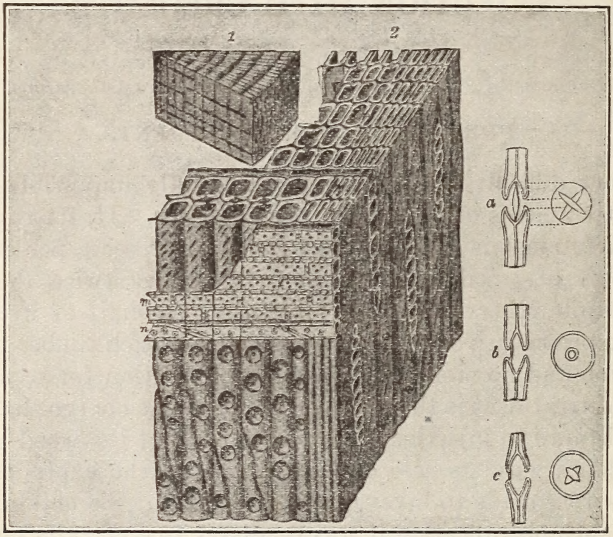


FIG. 1.—Wood of spruce. 1, natural size; 2, small part of one ring magnified 100 times. The vertical tubes are wood fibers, in this case all "tracheids." *m*, medullary or pith ray; *n*, transverse tracheids of pith ray; *a*, *b*, and *c*, bordered pits of the tracheids, more enlarged.

one part of the cross section and heartwood in another part. In some species (those of *Abies*, *Tsuga*, and *Picea*) there is no sharp color distinction between the sapwood and heartwood.

The concentric rings, each of which represents one year's growth, also vary in thickness in different trees and in different parts of the same tree. Each ring consists of two portions; one is an inner, softer, lighter-colored portion formed early in the season, called springwood; the other is an outer, firmer, and darker-colored portion, formed late in the season and called summerwood. In some species, as in longleaf pine, the dark summerwood appears as a distinct, sharply defined band, constituting 50 per cent or more of the cross section; in other species, as in white pine, the springwood passes gradually into the darker summerwood.

MICROSCOPIC STRUCTURE.

The structure of wood is illustrated diagrammatically in figure 1, while Plates I, II, and III are photographs of magnified sections seen in transverse, radial, and tangential planes, respectively.

TRACHEIDS.

The fibers called "tracheids," forming the greater portion of the wood, are between one-twentieth and one-fifth of an inch long, or from 40 to 100 times their radial diameter. They are tapered and closed at their ends. (Pls. II and III.) In the springwood the tracheids have thin walls and large cell spaces, and are polygonal or rounded in form; in the summerwood they have thick walls and small cell spaces, and are flattened radially. (See fig. 1 and Pl. I.) Located on the walls of the tracheids are numerous circlet-like structures, the "bordered pits," which are plainly visible in Plates II and III. These pits or pores are partitioned off by the "pit membrane," the central portion of which is thickened, and is known as the torus. Owing to the peculiar overhanging contour of the border, the orifice of the bordered pit, where it opens to the cell cavity, is of much smaller diameter than where it abuts on the pit membrane. (Fig. 1, *a*.) When the membrane is forced toward one of the two cell lumina, which it separates, the thickened portion or torus is capable of blocking the narrow opening, and thus acting as a valve. (Fig. 1, *b*.) In the heartwood the torus often is permanently displaced from its central position and is sometimes cemented to one side or other of the pit, effectually blocking it.

MEDULLARY RAYS.

The cells of the medullary rays are smaller and much shorter than the longitudinal tracheids and lie with their long axis at right angles to the latter. These ray cells are distinguished by their abrupt ends, thin walls, numerous simple pits,[1] and by their short length, only 8 to 10 times their diameter. They are seen as bands on the radial face (Fig. 1 and Pl. III), and as pores on the tangential face. (Pl. II.) Although quite small in the conifers they can be seen readily without a magnifier on the radial surface.

RESIN CELLS.

Many of the conifers contain what are known as resin cells. These resemble the ray cells in general appearance, but, except for those in the medullary rays themselves, have their long axes parallel with the major axis of the tree.

[1] Simple pits do not have the circlet-like border. They are simple openings in the cell walls closed only by the pit membranes.

RESIN CANALS.

In many species numerous large openings known as "resin canals" exist. (Pl. I.) These passages are intercellular spaces, surrounded by so-called "epithelial cells," the chief sources of resin production in the tree. In a less number of species these canals occur within the medullary rays, there known as "fusiform rays." These radial canals intersect the longitudinal ones and thus form a partially complete network of resin ducts penetrating all portions of the wood. Resin ducts in pines are sometimes wholly or partially blocked by growths called tyloses.

DISTRIBUTION OF RESIN STRUCTURES.

With very few exceptions, all of the conifers contain either resin cells or resin canals, and some species contain both. The distribution of resin cells varies in different species; in some they are scattered through the wood, while in others they are concentrated in zones. The character and number of the resin canals also vary greatly. Those in some species, as in Douglas fir, are few in number, are small, and have frequent constrictions tending to close the canal; those in other species, as in longleaf pine, are abundant, large, and entirely without constrictions.

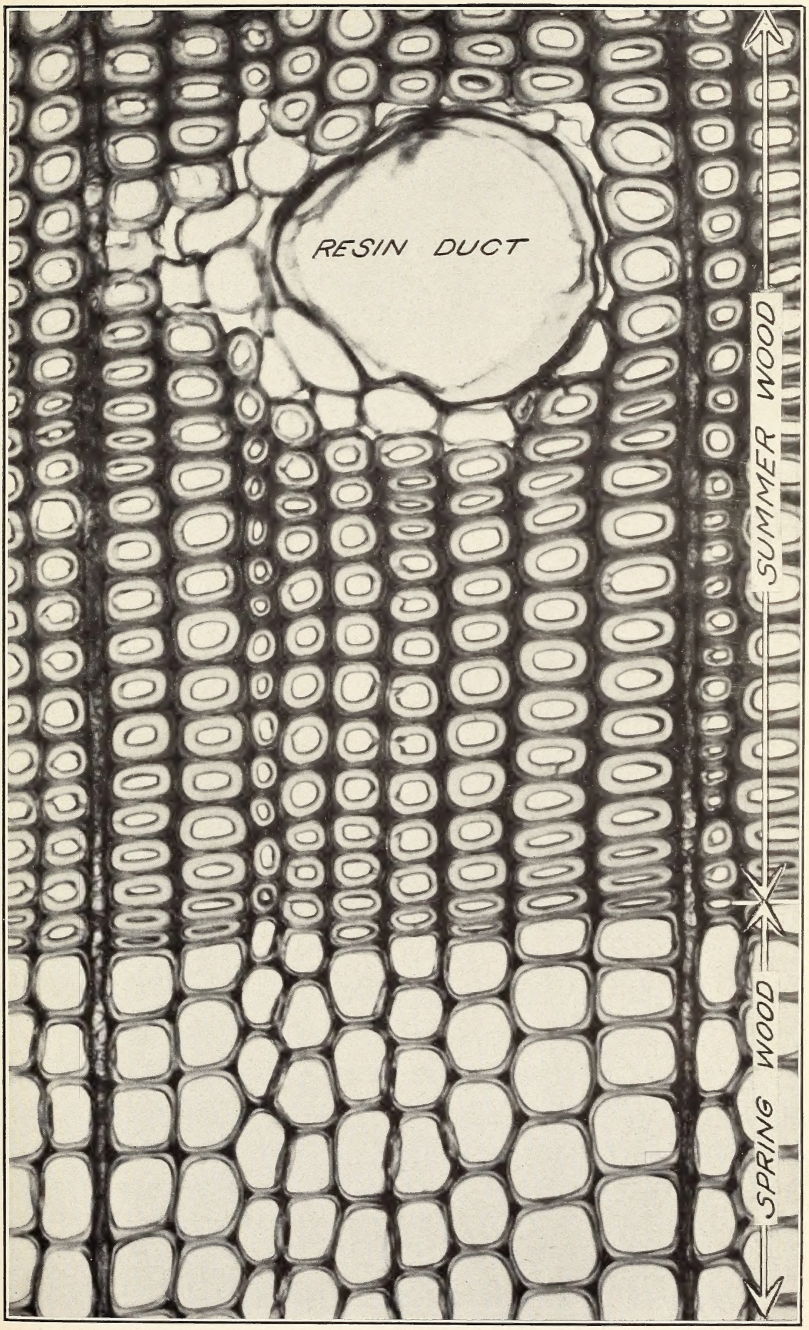
EXPERIMENTAL METHODS.

The presence of resin canals and cells in the wood and the character of these structures at once suggest that they may have a considerable influence on the manner in which the wood takes impregnation with preservatives. A considerable portion of the experimental work was given to determining the extent of this influence.

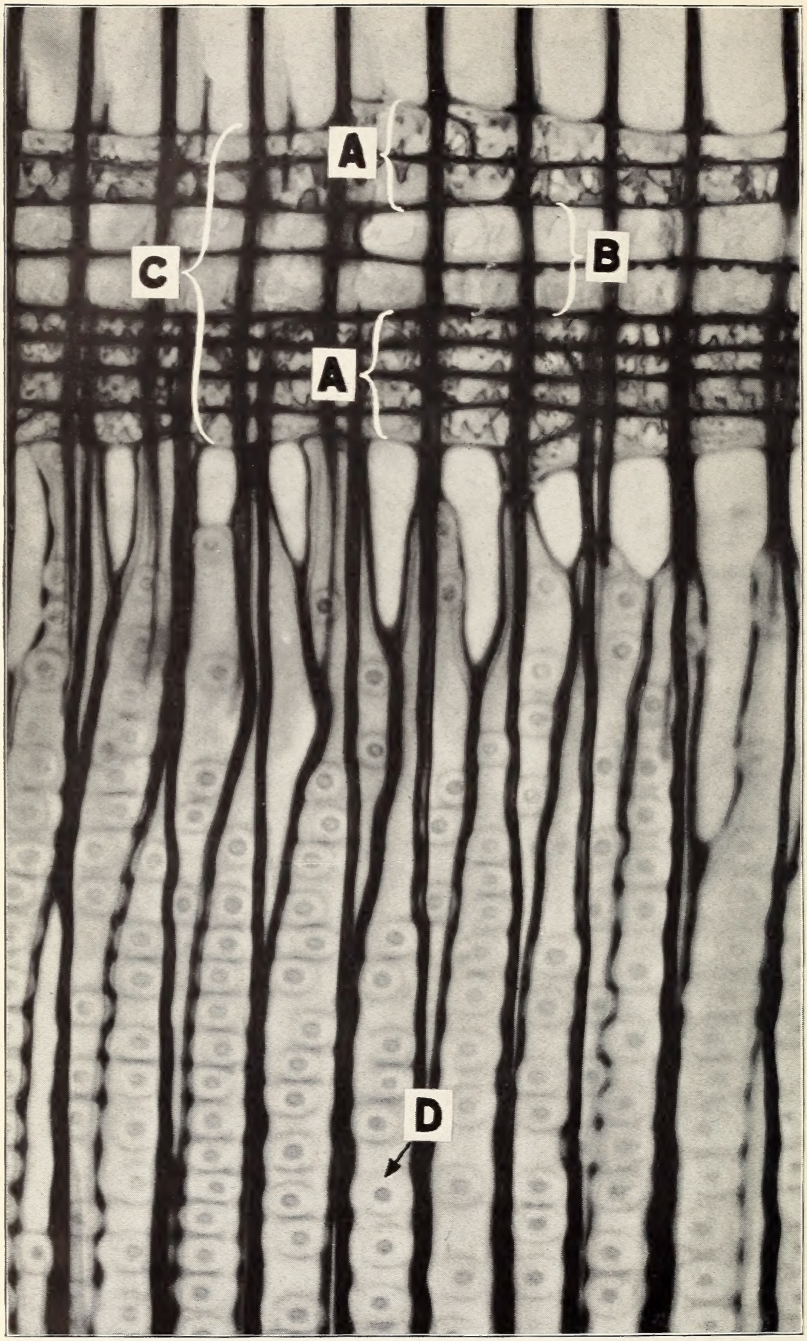
The resistance of the wood to treatment was determined by two forms of tests: (1) by applying the creosote to a small area on a specimen and measuring the penetration in different directions; and (2) by impregnation in a treating cylinder. In the latter tests blocks from each of the species were treated together in the same run.

APPARATUS.

The "penetrance apparatus," illustrated in figure 2, was designed for the first class of tests. The wood under test, which had a 1-inch hole bored in it, was clamped against the open end of the pipe A leading to the bottom of a pressure tank B. The pipe and lower portion of the tank were filled with creosote. Pipe C, opening into the top of the tank, was connected with an air reservoir in which a pressure was maintained. When desired, air under pressure was turned into tank B, which thus placed the preservative under pressure. The apparatus was surrounded by a wooden oven, as shown, with double



TRANSVERSE SECTION OF SHORTLEAF PINE (PINUS ECHINATA). (MAGNIFICATION 250 DIAMETERS.)



RADIAL SECTION OF SHORTLEAF PINE (PINUS ECHINATA). (MAGNIFICATION 250 DIAMETERS.)

A, ray tracheids; **B**, ray cells; **C**, medullary ray; **D**, bordered pits.

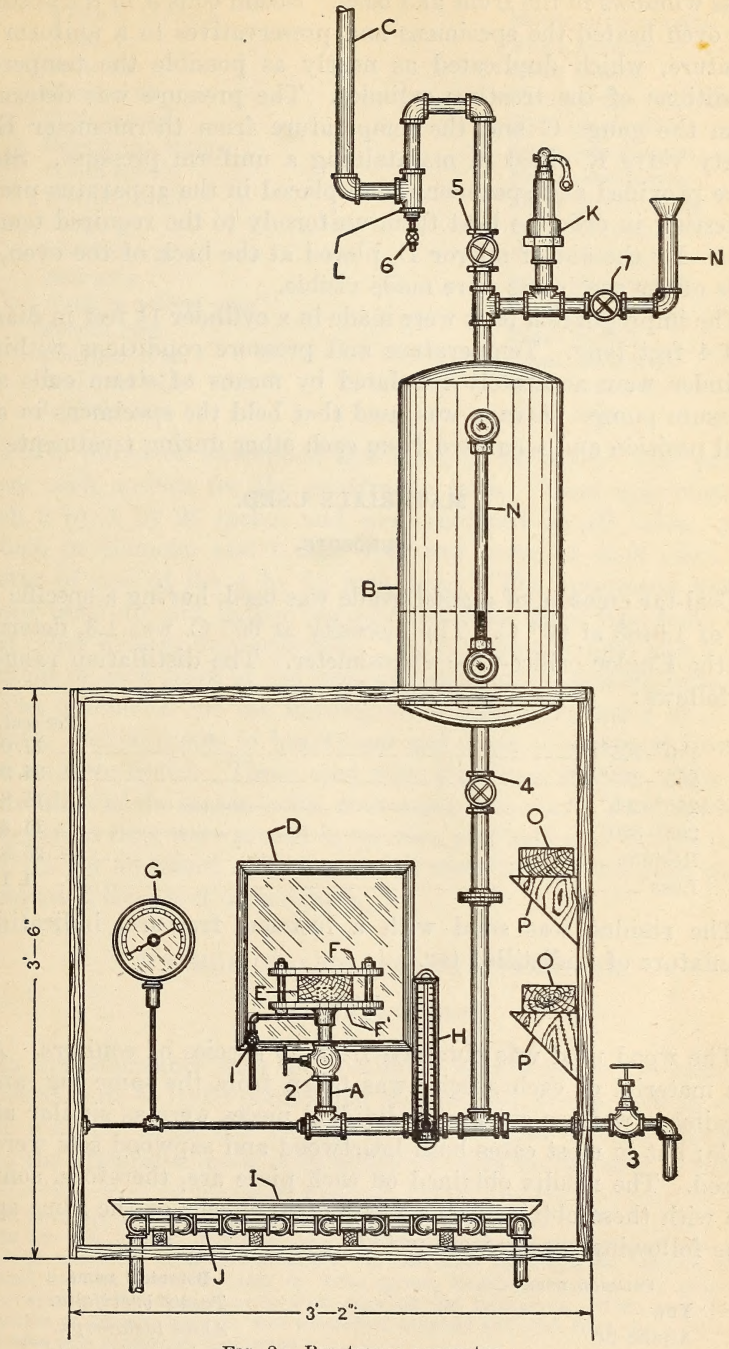


FIG. 2.—Penetrance apparatus.

glass windows in the front and back. Steam coils J in the bottom of the oven heated the specimens and preservatives to a uniform temperature, which duplicated as nearly as possible the temperature conditions of the treating cylinder. The pressure was determined from the gauge G and the temperature from thermometer H. A safety valve K aided in maintaining a uniform pressure. Shelves were provided and specimens were placed in the apparatus previous to testing in order to heat them uniformly to the required temperature. By the aid of mirror D, placed at the back of the oven, both ends of the specimens were made visible.

The impregnation tests were made in a cylinder 1½ feet in diameter and 4 feet long. Temperature and pressure conditions within the cylinder were accurately regulated by means of steam coils and a pressure pump. A cage was used that held the specimens in a vertical position and separated from each other during treatment.

MATERIALS USED.

CREOSOTE.

Coal-tar creosote of a good grade was used, having a specific gravity of 1.0483 at 60° C. The viscosity at 60° C. was 1.3, determined by the Engler orifice-type viscosimeter. The distillation range was as follows:

	Per cent.
0°–205° C.	11.0
205°–255° C.	34.9
255°–295° C.	15.8
295°–320° C.	11.4
Residue	25.8
Loss	1.1

The residue was solid with a lustrous fracture, indicating an admixture of undistilled tar.

WOOD.

The wood used was obtained from 20 species of conifers. All of the material of each species was taken from the same log, and the specimens were so cut that individual pieces were as similar as possible; but in most cases both heartwood and sapwood sets were prepared. The results obtained on each piece are, therefore, comparable with those obtained on other like specimens of the same species. The following species were tested:

Common name.	Botanical name.
Yew	*Taxus brevifolia.*
Alpine fir	*Abies lasiocarpa.*
Eastern hemlock	*Tsuga canadensis.*
Big tree	*Sequoia washingtonia.*

Common name.	Botanical name.
Western hemlock	*Tsuga heterophylla.*
White fir	*Abies grandis.*
Noble fir	*Abies nobilis.*
Douglas fir	*Pseudotsuga taxifolia.*
Sitka spruce	*Picea sitchensis.*
Engelmann spruce	*Picea engelmanni.*
White spruce	*Picea canadensis.*
Western larch	*Larix occidentalis.*
Tamarack	*Larix laricina.*
Lodgepole pine	*Pinus murrayana.*
Jack pine	*Pinus divaricata.*
Western yellow pine[1]	*Pinus ponderosa.*
Spruce pine	*Pinus glabra.*
Longleaf pine	*Pinus palustris.*
Shortleaf pine	*Pinus echinata.*
Loblolly pine	*Pinus tæda.*

Three pieces of heartwood and three of sapwood[2] were prepared from each species for the penetrance tests. These specimens were each 2 by 4 by 25 inches and were surfaced on all sides. A hole 1 inch in diameter and 1 inch deep was bored in each piece at the center of one of the 4 by 25 inch faces. The specimens were seasoned until air dry before testing, and only those free from checks and other defects were selected. The oven-dry weight and moisture content of each piece at the time of treatment were determined.

The specimens for the impregnation tests were cut 2 by 2 by 12 inches. Seven pieces of heartwood and seven of sapwood from each species were tested. Those used were free from defects. The pieces were allowed to season until thoroughly air dry. Just before impregnation they were placed in an oven and held at a temperature of 100° C. for 48 hours. This rendered them practically oven dry and eliminated the effect of moisture.

METHOD OF APPLYING THE CREOSOTE.

PENETRANCE TESTS.

In the penetrance tests the specimens were subjected to creosote at a pressure of 85 to 90 pounds per square inch, the maximum obtainable with the apparatus employed. The length of time required to heat the apparatus made it necessary to carry on the tests at tempera-

[1] A tree from California and one from Montana were tested.

[2] In the case of yew, tamarack, and western larch the sapwood was so thin that no sapwood specimens could be obtained. In the cases of Alpine fir, eastern hemlock, western hemlock, white fir, noble fir, Sitka spruce, Engelmann spruce, and white spruce there was no color distinction between sapwood and heartwood. Wood from the outer 2½ inches of growth, however, was considered sapwood and that from the portion within this area was considered heartwood.

tures between 120° and 160° F. Readings of temperature and pressure were made every 10 minutes.

The specimens were removed after definite periods and the time noted when oil first penetrated a surface. Three periods were taken, one-half hour, one hour, and two hours. One of each set of three specimens was treated for each of these periods. The measured penetrations of the various species are, therefore, directly comparable with each other.

The wood of some of the specimens was completely penetrated within a few seconds. This was true of the sapwood of some of the pines and, in a few cases, of the heartwood also. When this occurred, the pieces were removed as soon as penetrated, instead of at the end of the period.

The treated pieces were sawed transversely and longitudinally along the center lines (Pl. IV, fig. 1) and the sawed surfaces immediately coated with collodion to prevent the creosote from staining the untreated surface. The maximum penetration of oil in longitudinal, tangential, and radial directions was measured to the nearest 0.01 inch and the average penetration in each direction estimated as closely as possible. Each specimen was photographed.

IMPREGNATION TESTS.

The specimens prepared for impregnation tests were separated into seven series, with one heartwood and one sapwood piece of each species in a series. Seven runs were made, in which all conditions of treatment except pressure were maintained as nearly uniform as possible. The conditions of treatment are given in Table 1.

TABLE 1.—*Conditions of treatment in impregnation cylinder.*

Run number.	Pressure.	Time of pressure.	Temperature of preservative.
	Lbs. per sq. in.	*Hours.*	°*F.*
1	25	1	175 to 185
2	50	1	175 to 185
3	75	1	175 to 185
4	100	1	175 to 185
5	125	1	175 to 185
6	150	1	175 to 185
7	Atmospheric.	1	175 to 185

All pieces were weighed before treatment, also within 1 hour after treatment, and again after 48 hours. The weights taken after 48 hours are the ones used in this report.

TANGENTIAL SECTION OF SHORTLEAF PINE (PINUS ECHINATA). (MAGNIFICATION 250 DIAMETERS.)

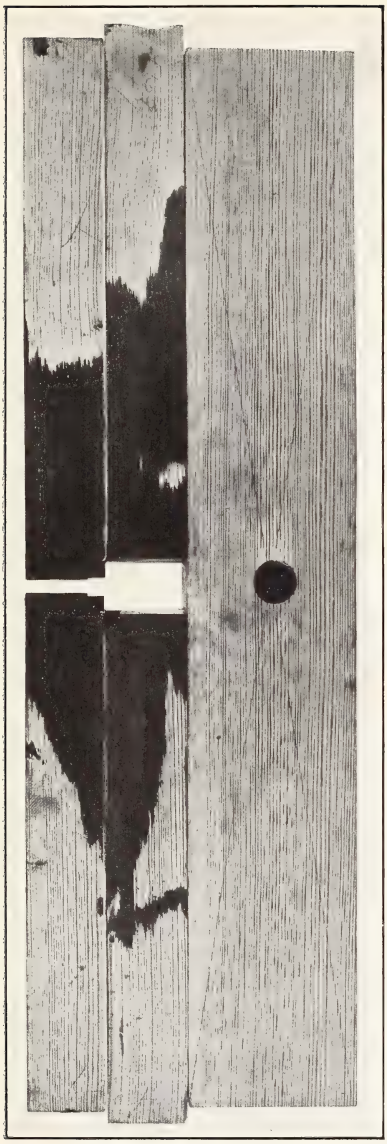


FIG. 1.—FORM OF SPECIMENS FOR PENETRANCE TESTS AND MANNER OF SAWING TO DETERMINE PENETRATIONS.

FIG. 2.—LONGLEAF PINE HEARTWOOD, TREATED IN CYLINDER.

The left half of this specimen shows the usual appearance of creosoted heartwood pine; the dark bands are heavily treated summerwood and the lighter ones are treated springwood. On the right side both summerwood and springwood are evenly treated. No difference could be detected in the wood with the microscope that might have caused a difference in the treatment. The right side is toward the pith of the tree.

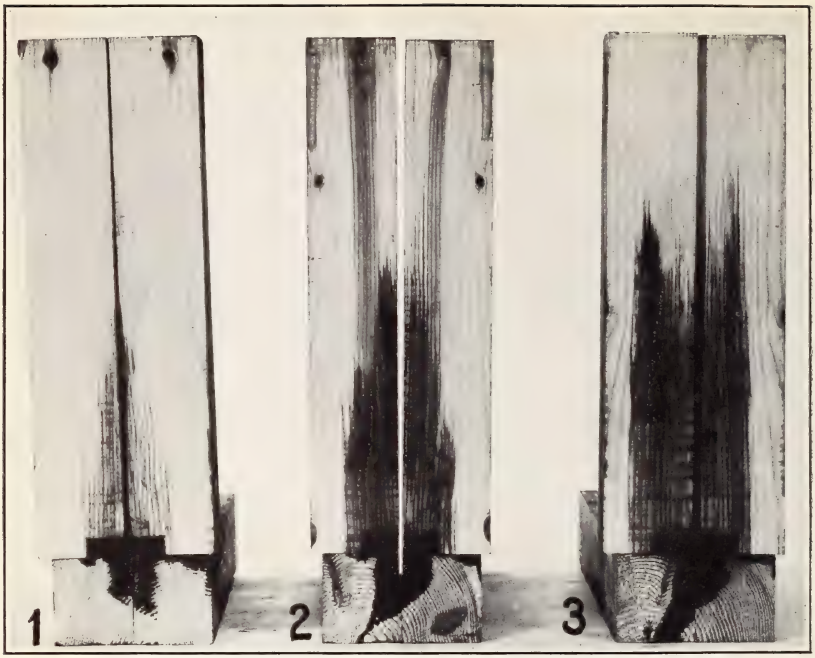


FIG. 1.—PENETRATIONS IN JACK PINE (PINUS DIVARICATA) HEARTWOOD.

1, piece No. 296, treated 30 minutes; 2, piece No. 298, treated 60 minutes; 3, piece No. 297, treated 120 minutes. The structure surrounding the resin ducts was easily penetrated, allowing the heartwood to be satisfactorily treated. Note the well-defined radial penetration which followed the radial ducts toward the pith.

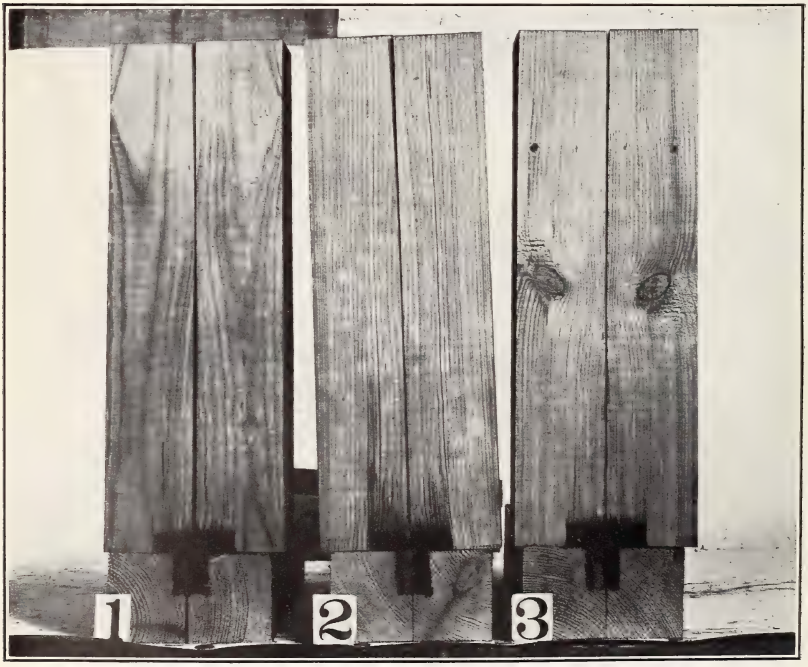


FIG. 2.—PENETRATIONS IN TAMARACK (LARIX LARICINA) HEARTWOOD.

1, piece No. 312, treated 30 minutes; 2, piece No. 313, treated 60 minutes; 3, piece No. 311, treated 120 minutes. This is a good example of a species containing resin ducts that may be easily impregnated, but in which the nonresin structure is almost impenetrable. Note the absence of radial or tangential penetration.

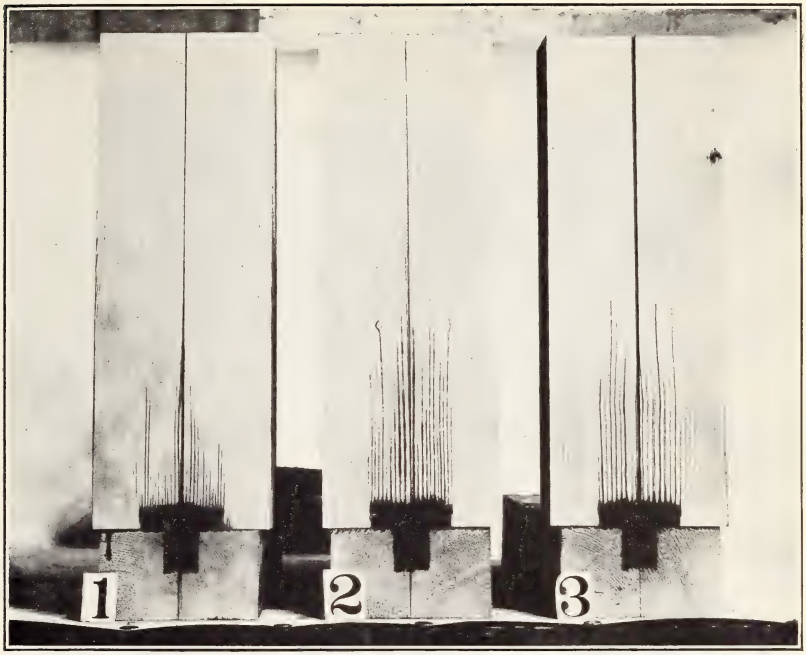


FIG. 1.—PENETRATIONS IN EASTERN HEMLOCK (TSUGA CANADENSIS) HEARTWOOD.

1, piece No. 256, treated 30 minutes; 2, piece No. 265, treated 60 minutes; 3, piece No 259, treated 120 minutes.

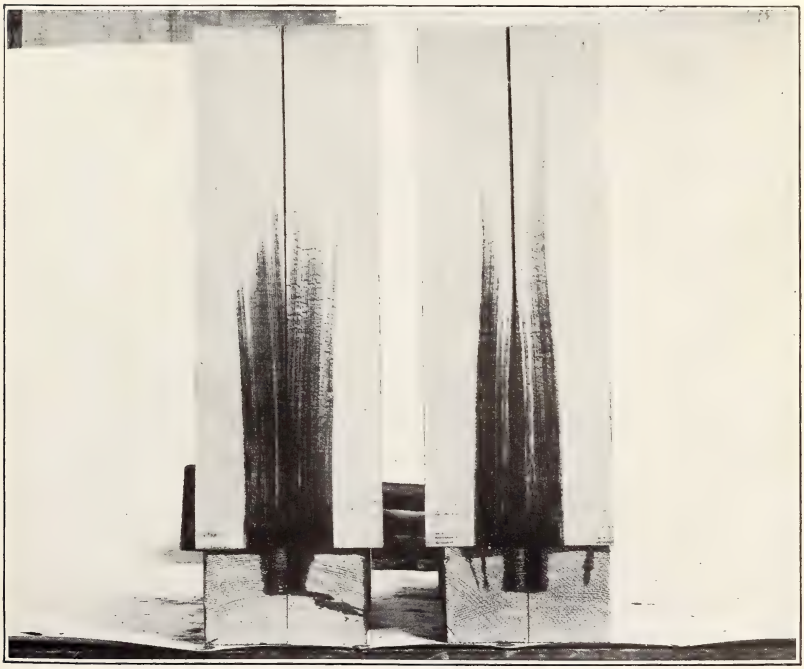


FIG. 2.—PENETRATIONS IN EASTERN HEMLOCK (TSUGA CANADENSIS) SAPWOOD.

1, piece No. 251, treated 30 minutes; 2, piece No. 254, treated 60 minutes. Eastern hemlock is a good example of an easily treated wood that contains no resin ducts. The resin cells had little effect on the penetration. Note the similarity of the treatment in the sapwood and heartwood.

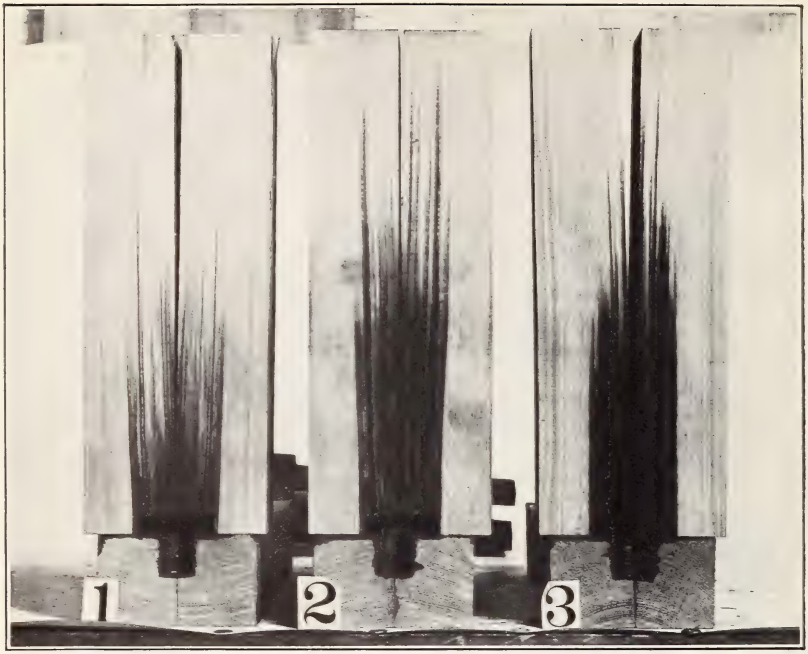


FIG. 1.—PENETRATIONS IN ALPINE FIR (ABIES LASIOCARPA) HEARTWOOD.

1, piece No. 308, treated 30 minutes; 2, piece No. 307, treated 60 minutes; 3, piece No. 309, treated 120 minutes. This species contained no resin ducts or cells and is almost impenetrable.

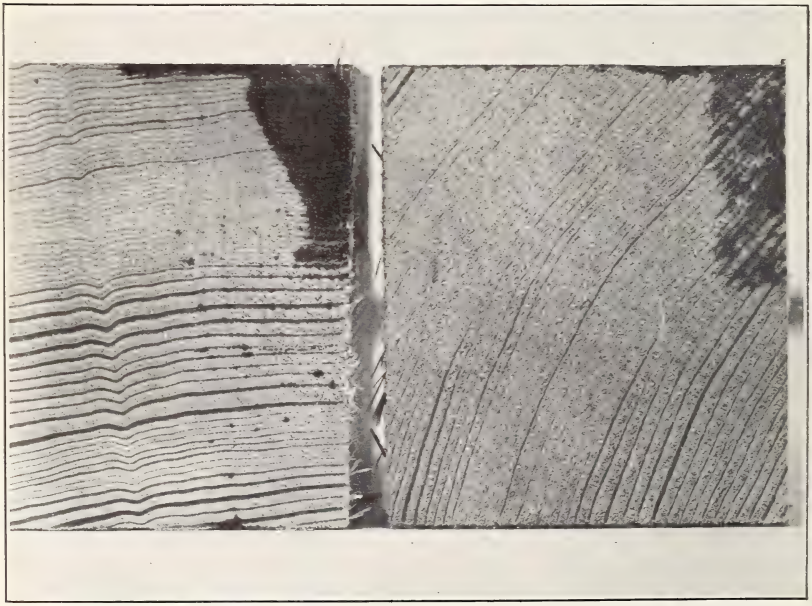


FIG. 2.—DOUGLAS FIR (PSEUDOTSUGA TAXIFOLIA) TREATED IN PENETRANCE APPARATUS.

The piece to the left is sapwood; that to the right is heartwood. The spots on the sapwood piece are treated resin ducts outside of the range of ordinary penetration. They show that the creosote must have penetrated radially and then longitudinally. Most of the spots are in the summerwood.

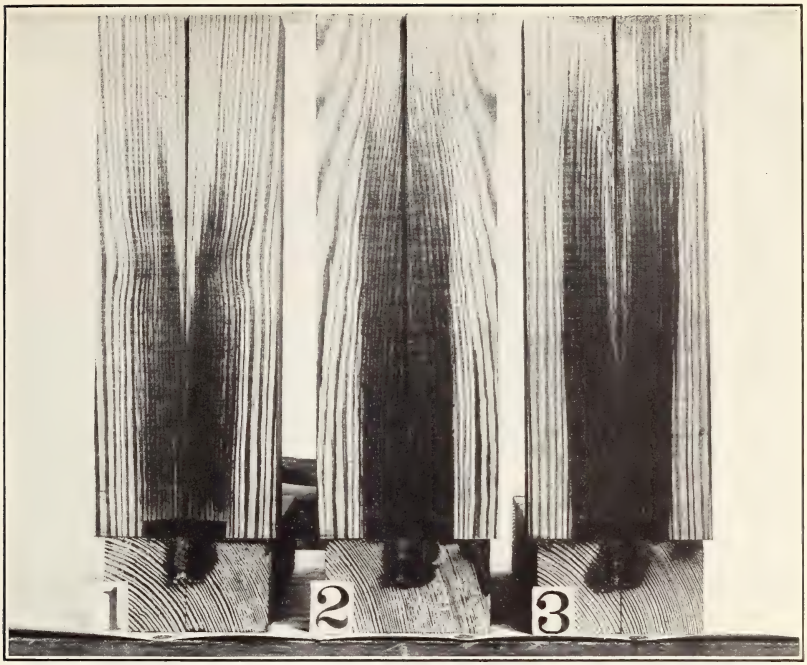


FIG. 1.—PENETRATIONS OF LONGLEAF PINE (PINUS PALUSTRIS) HEARTWOOD.

1, piece No. 248, treated 30 minutes; 2, piece No. 135, treated 60 minutes; 3, piece No. 242, treated 120 minutes.

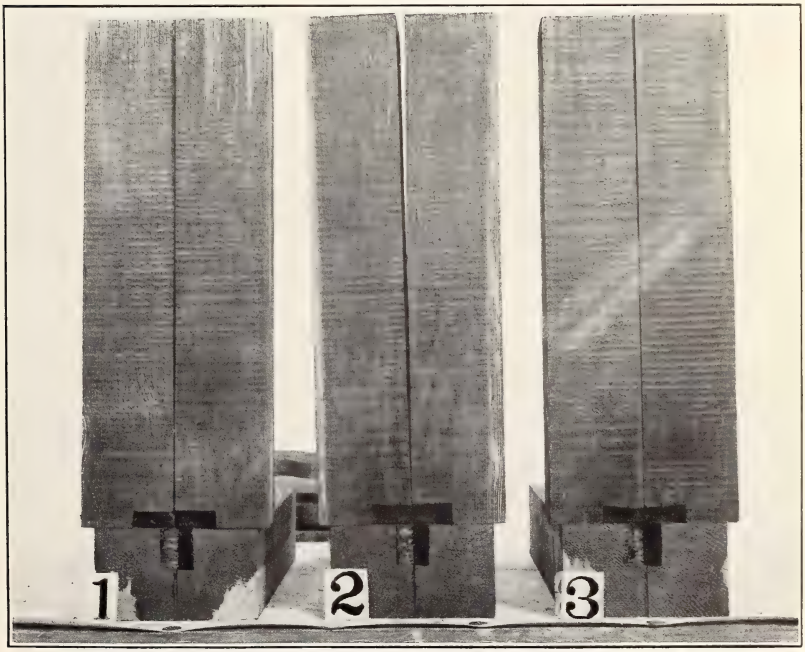


FIG. 2.—PENETRATIONS IN LONGLEAF PINE (PINUS PALUSTRIS) SAPWOOD.

1, piece No. 143, treated 45 seconds; 2, piece No. 136, treated 45 seconds; 3, piece No. 202, treated 45 seconds. The appearance of these specimens is typical of treated southern pines; very similar results were obtained with shortleaf, loblolly, and spruce pines. Note the difference in appearance of heartwood and sapwood.

PENETRATION AS AFFECTED BY WOOD STRUCTURE.

PENETRATION IN THE RESIN STRUCTURES.

The resin ducts were first thought to be the most important factor in the penetration of wood by creosote. It was soon found, however, that this was not the case; many species that had well-developed systems of resin ducts proved much more difficult to impregnate than others that had none. Thus the heartwood of Douglas fir and tamarack, both of which have highly developed radial and longitudinal ducts, proved extremely resistant to impregnation, while eastern hemlock, white fir, and other species, having no resin ducts, proved fairly easy to penetrate. Close examination showed that the resin ducts of the former received the oil but that the wood surrounding the ducts was not penetrated. (See Pl. V, fig. 1.) Thus the question of penetration in the wood fibers was shown to be of fundamental importance, while that in the ducts was of secondary importance.

On the other hand, when the wood fibers themselves were readily penetrable a system of resin ducts became of great importance. These ducts, forming a network of passages through the wood, caused the oil to be applied at numerous points within the wood, as well as on the surface, and in this manner greatly facilitated penetration of the entire structure. (Pl. V, fig. 2.)

PENETRATION IN RADIAL, TANGENTIAL, AND LONGITUDINAL DIRECTIONS.

WHEN NO RADIAL RESIN DUCTS WERE PRESENT.

In this case the penetration longitudinally was between 20 and 120 times as great as the penetration radially or tangentially.

When the oil was applied under pressure to a small area on the surface of a hemlock board 12 inches long, 3 inches wide, and one-half inch thick, it would appear at either end of the board before it would pass through one-half inch of wood radially. Much difference was found in the longitudinal penetration of such species. Eastern hemlock (Pl. VI) is an excellent example of easily penetrated wood which contains no resin canals, while Alpine fir (Pl. VII, fig. 1) is an example of a species having similar structure but very resistant to impregnation.

WHEN RADIAL RESIN DUCTS WERE PRESENT.

In this case the oil followed the ducts and spread longitudinally in each summerwood band as it was traversed. Also at numerous intersections of the radial and longitudinal ducts the oil changed its course and penetrated longitudinally. (Pl. VII, fig. 2.) In this case the average radial penetration varied from one-fourth to three-fourths of the average longitudinal penetration.

PENETRATION IN SAPWOOD AND HEARTWOOD.

The sapwood was much more easily penetrated than the heartwood in those species having highly developed resin systems, such as Douglas fir, larch, tamarack, and the spruces and pines. Species having no resin ducts treated but little better in the sapwood or outer portion than in the heartwood or inner portion. But the latter tendency does not always hold, since cedars, cypresses, and other woods (which were not here tested) are known to be more easily treated in the sapwood. These species have, however, a distinct color difference between heartwood and sapwood.

It is true that the harder and more insoluble resin in the ducts of the heartwood adds to the difficulty of penetrating heartwood. The great ease of penetration of the sapwood of pines, spruces, and other species seemed to be a property of the nonresin structure which, in conjunction with the resin ducts, rendered these woods very susceptible to treatment.

PENETRATION IN SPRINGWOOD AND SUMMERWOOD.

It was found in most species that the summerwood was more penetrable than the springwood. But this rule did not hold for redwood, yew, and tamarack. Redwood not only treated more easily in the springwood, but the summerwood was scarcely penetrated. In the yew and tamarack the springwood and summerwood were about equally resistant. In all other species tested the dense summerwood was the portion penetrated first, and usually the tracheids last formed, those with the thickest walls and smallest lumen, were the most penetrable.

The summerwood not only permitted the oil to enter more quickly and penetrate farther than did the springwood, but actually absorbed a greater amount of it. This last fact was indicated by the difference in color between treated summerwood and treated springwood. It was shown also in the case of a treated specimen of loblolly pine, in which, by actual determination, the summerwood contained 80 per cent more oil than the springwood.

In no case was any stick of wood absolutely impermeable. The springwood of the most impermeable species could always be penetrated longitudinally for three or more tracheids from the point of application of the pressure. (Pl. VII, fig. 1.)

PENETRATION IN THE MEDULLARY RAYS.

Except in the case of ray ducts the medullary rays, as a rule, were not penetrated. In some of the spruces, however, the upper and lower ray tracheids were penetrated and in some of the pines the entire ray. In no case except the spruces and pines was any penetration noted in the rays unless the specimen was very heavily treated.

GROUPING OF SPECIES.

GROUPING WITH RESPECT TO PENETRATIONS AND ABSORPTIONS.

Table 2 gives the average longitudinal and radial penetrations[1] and the absorptions obtained in the penetrance and impregnation tests, respectively. The species are arranged in order of the longi-

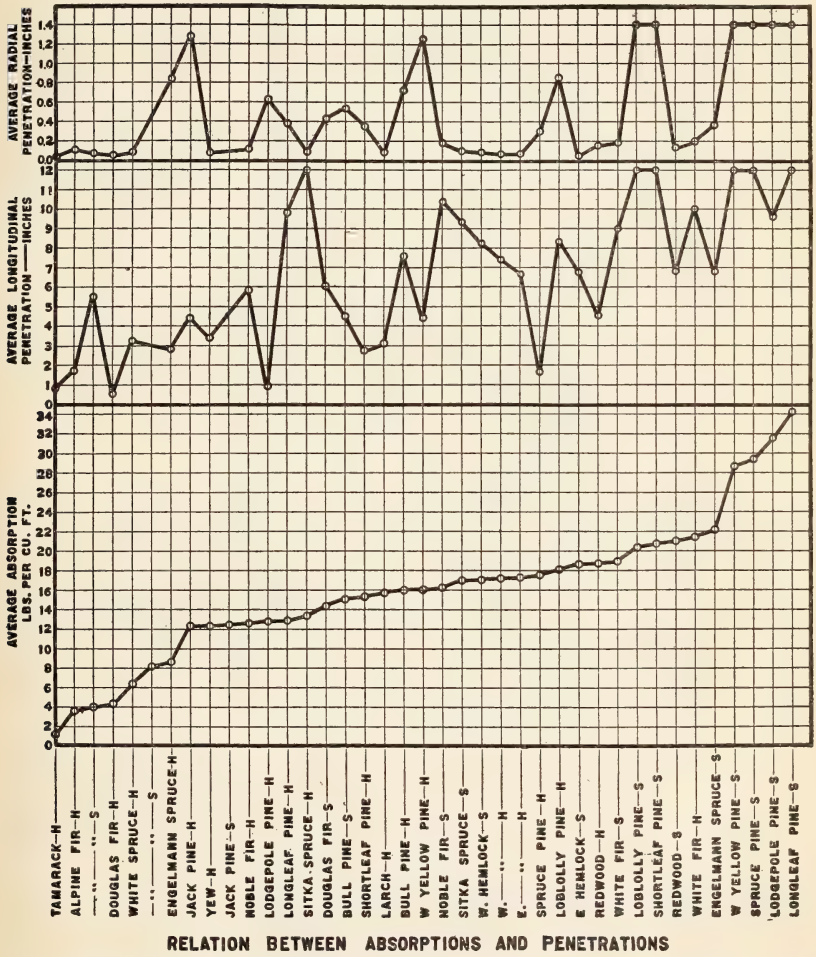


FIG. 3.—Relation between absorption and longitudinal and radial penetration. (Species platted in order of magnitude of absorptions.) (S=sapwood; H=heartwood.)

tudinal penetrations, beginning with the least; the order in respect to radial penetration and absorption, respectively, is indicated numerically, each in a separate column. The relation between absorption and penetration is shown more clearly in figure 3, in which the absorption and corresponding radial and longitudinal penetrations

[1] In obtaining average penetrations only the region in direct line with the pressure was taken into account.

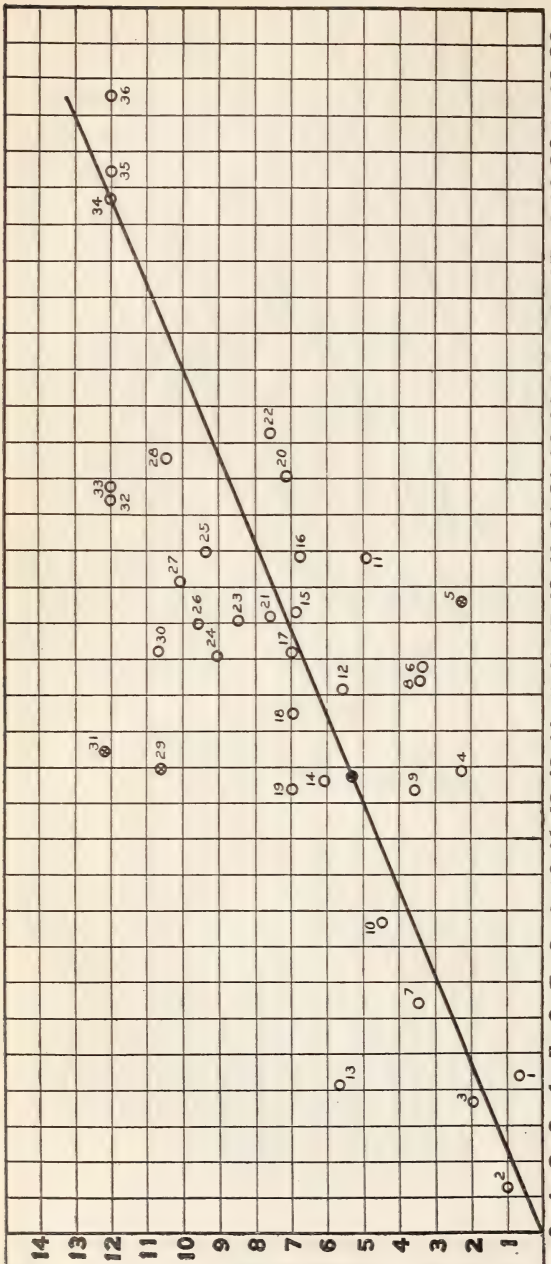


FIG. 4.—Relation of absorption to chemical, radial, and longitudinal penetrations.

1. Douglas fir—Heartwood.
2. Tamarack—Heartwood.
3. Alpine fir—Heartwood.
4. Lodgepole pine—Heartwood.
5. Spruce pine—Heartwood.
6. Western larch—Heartwood.
7. White spruce—Heartwood.
8. Shortleaf pine—Heartwood.
9. Yew—Heartwood.
10. Engelmann spruce—Heartwood.
11. Redwood—Heartwood.
12. Bull pine—Sapwood.
13. Alpine fir—Sapwood.
14. Noble fir—Heartwood.
15. Eastern hemlock—Heartwood.
16. Eastern hemlock—Sapwood.
17. Western yellow pine—Heartwood.
18. Douglas fir—Sapwood.
19. Jack pine—Heartwood.
20. Redwood—Sapwood.
21. Western hemlock—Heartwood.
22. Engelmann spruce—Sapwood.
23. Western hemlock—Sapwood.
24. Bull pine—Heartwood.
25. White fir—Sapwood.
26. Sitka spruce—Sapwood.
27. Loblolly pine—Heartwood.
28. White fir—Heartwood.
29. Longleaf pine—Heartwood.
30. Noble fir—Sapwood.
31. Sitka spruce—Heartwood.
32. Loblolly pine—Sapwood.
33. Shortleaf pine—Sapwood.
34. Western yellow pine—Sapwood.
35. Spruce pine—Sapwood.
36. Lodgepole pine—Sapwood.

are platted in order of the magnitude of the absorptions. The general tendency of the longitudinal penetrations is to increase as the absorptions increase, but the curve is very irregular. The radial penetrations show even less relation to the absorptions than do the longitudinal penetrations, but inspection of the figure shows that a few of the irregularities would be eliminated by combining the two penetration curves. In other words, a high longitudinal penetration and a low radial penetration may accompany a moderate absorption. Figure 4 shows the relation of absorptions to the combined radial and longitudinal penetrations in a slightly different manner. The absorptions are platted against a quantity obtained by adding twice the radial penetration to the longitudinal penetration.[1]

Although the average curve indicates a constant ratio between penetrations and absorptions, the variation of the individual points from the average is again very marked. Reasons for this behavior were frequently apparent upon examination of the treated sticks. For example, when the creosote followed merely the summerwood band of the annual rings, much less oil was required for a given penetration than when the entire ring was saturated.

GROUPING WITH RESPECT TO TREATMENT.

While it is desirable to have classifications based upon elementary characteristics rather than upon empirical results, it has been found that the development of the resin canals and cells, which form the most tangible structural differences between the conifers, is insufficient to grade these woods for preservative treatment. The following method of classification, based upon both empirical results upon air or oven-dry wood and structural characteristics, is therefore proposed:

A. Species in which the wood other than the resin structures treats with great difficulty or is impenetrable:
   1. Containing no resin ducts, Class I.
   2. Containing resin ducts, Class II.

B. Species in which the wood treats easily:
   1. Containing no radial ducts, or radial ducts not easily penetrable, Class III.
   2. Containing easily penetrable radial ducts.
      a. In the heartwood, Class IV.
      b. In the sapwood, Class V.

The division is primarily between species which treat with difficulty and those which treat easily. As a basis for this distinction

[1] Since the radial and tangential surfaces of the sticks treated in the absorption tests amounted to 12 times the end surface, it might be considered that the penetrations in the two directions should be combined in this ratio, assuming that radial and tangential penetration is equal and that absorption is proportional to surface area. By actual computation, however, this method seemed to give too much weight to radial penetration; and further trial showed that twice the radial penetration added to the longitudinal penetration gave the most nearly constant relation to the absorption.

it was necessary to adopt some standard by which the classification could be made. The wood was considered easily treated if, under the conditions of these tests, it fulfilled any one of the following conditions:

1. Received an average longitudinal penetration of more than 6 inches.[1]
2. Received an average radial penetration of more than 0.30 inch.[1]
3. Received an average absorption of more than 15 pounds per cubic foot.[2]

While this basis of classification is to a large extent arbitrary, the specification in regard to radial penetration divides the species which were penetrated by means of the radial ducts from those which were not so penetrated. Woods penetrated radially are, of course, most suitable for treatment in all forms. It was considered, however, that the species which in these tests received an average longitudinal penetration of 6 inches or more are sufficiently penetrable to be treated in short lengths, even though the radial penetration is very slight. The clause in regard to absorption was intended to include, among the easily treated species, those which received a fairly good treatment in the impregnation tests, although neither the longitudinal nor radial penetrations determined in the penetrance apparatus were especially good. The only woods affected by this clause are the heartwood of redwood and of western larch.

The species falling in each of the five classes are given in Table 3, together with the penetrations and absorptions of each species. In this table sapwood and heartwood are considered as if separate woods.

Species in Classes I and II are not very suitable for preservative treatment. While Douglas fir is extensively treated, very severe processes are used. However, the sapwood of both tamarack and Douglas fir can be treated easily.

Species in Class III are not very suitable for treatment, except in short lengths, on account of the lack of radial penetration. However, western larch and Sitka spruce contain radial ducts and it is possible that by more severe treatments than were employed in the tests these ducts may be penetrated. If western larch be excepted, each species in this class includes both heartwood and sapwood, and such species may be treated therefore without regard to the amount of sapwood present.

Woods in Class IV permit of thorough treatment. While there is much variation in the penetrability of these species, all are capable of being penetrated readily.

The woods in Class V can be saturated with creosote in a very short time. All species in Class IV occur in Class V. In actual treating operations the amount and location of the sapwood will determine in which class a given timber shall be placed.

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[1] Determined by penetrance tests.
[2] Determined by impregnation tests.

GROUPING WITH RESPECT TO SUITABILITY FOR TREATMENT IN PARTICULAR FORMS.

In this sort of grouping the main considerations are whether or not the sapwood treats more easily than the heartwood, and whether the wood can be easily penetrated radially. Round forms, such as fence posts, mine props, telephone posts, and piling constitute one class, while sawed heartwood ties, bridge timbers, sawed mine timbers, and other dimension timbers constitute a second class. Paving blocks are considered separately.

ROUND TIMBERS.

The penetration of the sapwood in round timbers is more important than that of the heartwood, since the latter is inclosed by the former. Railroad ties in which the heartwood is not exposed by hewing or sawing may be considered as round timbers. Since round timbers to be treated must be penetrated radially through the resin ducts it is essential that all of the bark be removed before treatment. The results obtained in these experiments and the experience of the Forest Service generally indicate that the following species may be successfully treated in the round form:[1]

Engelmann spruce.
Douglas fir.
Tamarack.
Western larch.
All of the pines.

Species which received practically no radial penetration and, therefore, are not well adapted to treatment in the form of round timbers, include the following:

Alpine fir.
Yew.
Noble fir.
White fir.
Eastern hemlock.
Western hemlock.
Redwood.
Sitka spruce.

DIMENSION TIMBERS.

In dimension timbers the treatment of the heartwood is of chief importance, since the sapwood is generally removed at least from part of the faces. These experiments indicate that—

Species in Class I are entirely unsuitable for treatment in the form of dimension timber.

Species in Class II are also unsuitable for this purpose, but may be treated under very severe pressure.

Species in Class III are not especially suitable for treatment as dimension timbers, but satisfactory results are being obtained in practice.

[1] Probably also the cedars and cypresses. No data have been obtained on these, however.

Species in Class IV are admirably adapted for this class of timbers. The presence of radial resin ducts with the easily penetrated wood structure makes possible the penetration radially of a large portion of the volume of such timbers.

If there is considerable difference in the penetrability of heartwood and sapwood, dimension timbers are best treated when all of the sapwood is removed. There is no advantage in protecting parts of a timber by heavily treated sapwood if other exposed parts have only the lighter treatment possible in the heartwood. Such treatments result in a practical loss of most of the oil absorbed by the sapwood which may represent a very large proportion of the cost of treating this kind of timber. A system of selecting timbers in accordance with their suitability for treatment may prove very profitable to the user of such timber.

PAVING BLOCKS.

These experiments indicate that with the possible exception of Alpine fir and the heartwood of Tamarack,[1] a fairly thorough penetration of the conifers in any form less than 12 inches in length can usually be obtained. This fact is significant as regards treatment of paving blocks. However, since the springwood, as a rule, can not be thoroughly treated, woods with wide springwood bands should not be used for this purpose. Other factors, such as strength or wearing qualities, will of course greatly limit the number of species suitable for paving blocks.

THEORY OF PENETRANCE.

It is a disputed question whether the cell walls under treatment are permeable to creosote, or whether they contain openings through which the oil passes. The first supposition does not account for the very rapid penetration of certain species, nor does it account for the greater ease of penetration in the thicker walled summerwood tracheids than in the thin-walled springwood tracheids. As regards the second supposition, it has been suggested[2] that the minute slits which frequently occur in the cell walls of seasoned wood are the openings through which the oil passes. Seen in transverse section, these slits appear as V-shaped openings extending about midway through the wall. They extend spirally around the cell and there is the possibility that where the slits in adjacent walls cross each other the cell wall is sufficiently broken down to allow the passage of oil. Another possibility is that a rupture occurs in the pit membrane brought about by internal stresses of the wood during seasoning or otherwise. While it seems that such ruptures are likely to occur, there is little or no evidence to support this hypothesis.

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[1] Tamarack blocks will take a good treatment in the green condition after steaming.

[2] The Physical Structure of Wood in Relation to the Penetrability, by H. D. Tiemann; Bull. 120, Am. Ry. Eng. and Main. of Way Association, January, 1910.

No satisfactory theory has yet been offered to explain the penetration of wood by creosote. The following observations, based on the experiments described in this bulletin, indicate the variety of phenomena which such a theory would have to take into account.[1]

1. The summerwood in the conifers was, as a rule, easier to penetrate than the springwood; but exceptions were noted, as (*Sequoia washingtonia*), which treated more easily in the springwood.

2. In the pines the summerwood was usually well penetrated, but the springwood penetrations were very erratic, often taking place very readily in some portions of the wood and with great difficulty in other portions of the same piece. (See Pl. IV, fig. 2.)

3. In most cases the resistance to penetration was least in the last-formed summer tracheids (having the thickest walls and the smallest cell cavities), and was greatest in the first-formed spring tracheids (having the thinnest walls and the largest cell cavities).

4. The color of the creosote oil in the springwood was often transparent and amber, while in the summerwood it was very dark.

5. In springwood apparently untreated the bordered pits frequently were strongly discolored and seemed to contain creosote.

6. In the pines, spruces, sequoia, larches, and Douglas fir the sapwood was more penetrable than the heartwood. In eastern and western hemlock and in the firs the sapwood and the heartwood were about equally penetrable.

7. As a rule, the medullary rays had no influence on penetrance, except when they contained resin ducts. Then they were usually very difficult to penetrate, but in *Picea* certain tracheids of the rays were readily treated, the upper and lower cells being usually the first. Frequently from these rays one or more longitudinal spring tracheids were penetrated. Sometimes all of the ray cells were penetrated, but never as heavily as the summerwood tracheids.

8. Of two sticks of wood similarly treated one was split immediately after treatment and the other several weeks later. They differed greatly in appearance. Springwood adjacent to treated summerwood in the first piece was apparently untreated, but in the second piece showed a marked discoloration. Microscopic examination of the latter showed that the cell walls were uniformly discolored.

CONCLUSIONS.

The following conclusions were drawn as a result of the tests described in this report:

1. Radial and longitudinal resin ducts penetrate intimately the interior of the wood and thus form passages for the preservative.

[1] Irving W. Bailey has recently published a paper in Vol. XI, No. 1, of the Forestry Quarterly which throws considerable light on this subject.

Radial resin ducts were found to be especially important. Where these occurred the wood was usually penetrated radially from one-fourth to three-fourths as far as longitudinally, and tangential penetration could usually be disregarded. Where no radial ducts were present, radial and tangential penetrations could be considered as equal, and they were found to be between one-twentieth and one one-hundred-twentieth of the longitudinal penetrations.

2. Absorption curves (see Appendix) platted for the specimens treated in the cylinder show that those species which were most difficult to impregnate gave the most uniform absorption results, and that the sapwood of those species containing resin ducts gave the most erratic absorption results. They showed also that sapwood of pines, as distinguished by its color from heartwood, was not always easier to treat than the heartwood. The color line in the wood does not necessarily separate the easily treated wood from the portions treated with difficulty. Some sapwood treated like heartwood and some heartwood treated like sapwood; all of these conditions are possible in the same cross section of a tree. As a consequence of this, the absorption curves for pines were, as a rule, very erratic, especially the sapwood curves.

3. The results obtained with a given species of wood can not always be applied to another species, however similar in structure the two may appear to be. This fact is strikingly evident in the treatment of heartwood larch and tamarack. Even woods of the same species show variations when grown under widely different conditions, as, for example, western yellow pine from California and from Montana.

Detailed results of the tests on each species are given in the Appendix.

APPENDIX.

DESCRIPTION OF SPECIMENS AND MANNER OF TREATMENT.[1]

YEW (TAXUS BREVIFOLIA).

The summerwood in the yew specimens was equal to about one-fourth of the width of the springwood. Resin cells and resin canals are entirely absent in this species.

The average oven-dry weight per cubic foot of eight heartwood specimens of yew was 38.5 pounds.

The penetration in both penetrance and cylinder treatments was found to take place equally in springwood and summerwood. Radial and tangential penetrations were also about equal. The average longitudinal penetration was about 50 times the average radial or tangential penetrations.

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[1] In describing the woods used in these tests the observations made on the specimens are in some cases supplemented by remarks on the general characteristics of the species taken from Penhallow's "North American Gymnosperms."

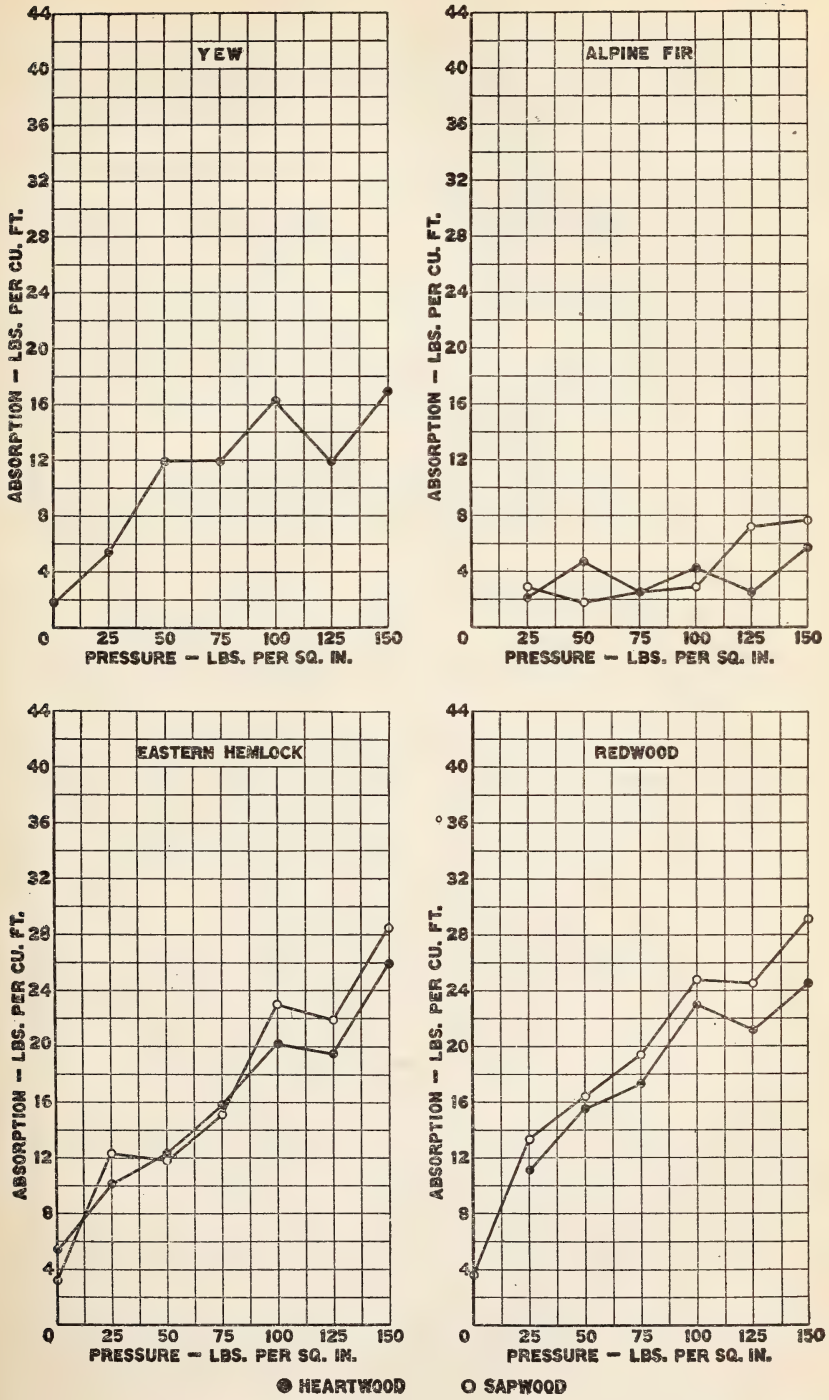

FIG. 5.—Absorption in the heartwood and sapwood of yew, Alpine fir, eastern hemlock, and redwood.

ALPINE FIR (ABIES LASIOCARPA).

The Alpine fir was very light, soft, close-grained, and compact. The growth rings were narrow and uniform in width, and the summerwood was thin. The springwood tracheids were large and had rather thin walls. Neither resin cells nor resin canals were present.

The average oven-dry weight per cubic foot of three sap specimens was 22 pounds, and of six heart specimens 22.2 pounds.

The penetration took place more readily in the summerwood than in the springwood, and in many cases only the last half dozen rows of tracheids of the summerwood were treated.

The character of penetration in the cylinder treatments was quite similar to that in the penetrance tests. Although the summerwood was often treated throughout the stick, in most cases only a few tracheids of the summerwood were penetrated. The springwood penetration averaged about 0.15 inch longitudinally. In some places, however, the springwood of several growth rings was treated to the center of the stick.

The sapwood apparently treated a little more easily than the heartwood, but the difference was so small as to be negligible. Radial and tangential penetrations were both of slight importance. The average longitudinal penetration was 60 to 70 times as great as the average radial and tangential penetrations.

EASTERN HEMLOCK (TSUGA CANADENSIS).

The summerwood of eastern hemlock was dense and was from one-fourth to one-half the width of the springwood. The latter had large and very thin-walled tracheids.

The average oven-dry weight per cubic foot of eight sap specimens was 20.7 pounds, and of eight heart specimens 22.7 pounds.

This species is simple in structure. It differs from the yew and Alpine fir, however, in having large but not numerous resin cells located in a single row on the outer face of the summerwood. Resin passages are never present.

The penetration took place more readily in the summerwood than in the springwood, but near the point of pressure the springwood was penetrated in some cases for 1 or 2 inches. The summerwood treated most quickly in the two to five last-formed rows of summer tracheids, and apparently the heaviest absorptions were along the zone of the resin cells. The line between the treated summerwood and the untreated adjacent springwood was very sharply defined.

The character of penetration in the cylinder-treated sticks was very similar to that in the penetrance specimens. The summerwood was in most cases treated to the center of the stick. The springwood was treated from 2 to 3 inches longitudinally.

Practically no difference either in absorption or penetration was noted between the heartwood and sapwood. Radial and tangential penetrations were of small importance. The longitudinal penetration averaged about 80 times the radial or tangential penetrations.

The influence of the resin cells on penetration was very difficult to determine. The creosote appeared to penetrate more easily in the summerwood tracheids lying adjacent to the resin cells, but the adjacent springwood tracheids were not treated.

A peculiarity of hemlock was its tendency to exude oil for many hours after treatment. This probably was due to the slow escape of confined air in the wood, which remained under a slight pressure for many hours after the release of external pressure.

REDWOOD (SEQUOIA SEMPERVIRENS).

In the redwood the summerwood was about one-third the width of the springwood. The latter was very open, with thin-walled tracheids. The resin cells were rather large, numerous, and scattered throughout the springwood.

Resin cysts, or aggregates of resin cells, were sometimes contiguous and coalescent and formed extended tangential series in the initial growth of the springwood of distant-growth rings. Often the cysts were separated longitudinally only by a wall of resin cells. Tyloses were sometimes present in the cysts.

The average oven-dry weight per cubic foot of four heart specimens was 20 pounds, and of seven sap specimens 19.3 pounds.

Penetration in general took place more readily in the springwood than in the summerwood, but the maximum penetrations were in the one to three last-formed summerwood tracheids and in the two or more first-formed springwood tracheids; that is, along the outer face of the summerwood in the zone of the resinous cells and cysts. In the portions treated most heavily the summerwood band was treated throughout, but usually it was penetrated very slightly.

The character of the penetrations in the cylinder treatments was very similar to that in the penetrance tests. Near the end of the stick the entire springwood of nearly every ring was penetrated, but near the center only the first-formed springwood tracheids were treated. The summerwood was usually treated for only a short distance from the ends.

In the sapwood penetration was somewhat quicker and absorption a trifle greater than in the heartwood. But these differences were so slight that they may be disregarded.

Radial and tangential penetrations were about equal. This indicated that tangentially extended series of resin cysts did not influence appreciably tangential penetration. The average longitudinal penetration was about 50 times greater than the average radial or tangential penetrations.

The influence of the resin structure was apparent in redwood. The creosote followed the resin zone more readily than the surrounding wood structure. A peculiarity of redwood was that the springwood was penetrated more easily than the summerwood, whereas with most other species the summerwood was more easily penetrated than the springwood.

WESTERN HEMLOCK (TSUGA HETEROPHYLLA).

The growth rings of western hemlock were narrow, with prominent summerwood bands usually about equal in width to the springwood, which consisted of large and thin-walled tracheids.

The average oven-dry weight per cubic foot of six heart specimens was 27 pounds, and of six sap specimens 28 pounds.

Resin cells were very prominent on the outer face of the summerwood. These sometimes united to form an imperfect resin passage. In other respects the western hemlock specimens were structurally similar to eastern hemlock.

Penetration took place more readily in the summerwood than in the springwood. In most cases the resinous portion (on the outer face of the summerwood) seemed to be penetrated first, the oil passing for a very short distance from this zone radially into both the summerwood and springwood. The summerwood band as a whole treated almost as easily as the resinous zone, and in many growth rings the summerwood was treated while the resin canals were untreated. The springwood was also uniformly penetrated, but not as far nor as heavily as the summerwood.

The character of penetration in cylinder-treated sticks was similar to that in sticks treated in the penetrance apparatus. The springwood treated longitudinally from 1 to 4 or 5 inches, while the summerwood was treated to the center of the stick in nearly every growth ring.

Practically no difference was noted either in penetration or absorption between the heartwood and sapwood. The average longitudinal penetration was about 90 or 100 times as great as the average radial or tangential penetrations.

WHITE FIR (ABIES GRANDIS).

The growth rings of white fir were usually very broad, with large and thin-walled springwood tracheids. Resin cells were few and scattering on the outer face of the springwood. Resin passages were not present. Structurally this species is very similar to eastern hemlock.

The average oven-dry weight per cubic foot of all heart specimens was 22 pounds, and of six sap specimens 22.7 pounds.

The greatest penetration took place in the last-formed summerwood tracheids, but the difference was not marked. Near the point of application of pressure both springwood and summerwood were equally treated, and at maximum penetrations even the springwood in many places was heavily treated. The heartwood was slightly easier to penetrate and absorbed somewhat more oil than the sapwood.

White fir contains no resin structures except simple resin cells, but it was nevertheless penetrated easily in both springwood and summerwood.

The average longitudinal penetration was about 50 times the average radial and 35 times the average tangential penetration.

NOBLE FIR (ABIES NOBILIS).

The summerwood of noble fir was about equal in width to the springwood. The spring tracheids were large and thin-walled. In distinct and widely separated growth rings, resin cells were localized to form imperfect resin canals, these occurring in somewhat continuous zones in the summerwood.

The average oven-dry weight per cubic foot of 10 heart specimens was 21.9 pounds, and of five sap specimens 23.6 pounds.

The maximum penetration took place along summerwood bands and more especially in the last-formed tracheids of the summerwood. In the most heavily treated zone, near the point of application of pressure, the entire summerwood was treated together with portions of the springwood.

The character of penetrations in the cylinder and in the penetrance treatments were very similar. The summerwood was nearly always treated to the center of the stick. Near the ends considerable springwood penetration was noted. In the sapwood more of the springwood was treated than in the heartwood.

The sapwood treated more quickly and absorbed more oil than the heartwood. Radial and tangential penetrations were of considerable importance, especially in the sapwood. The average longitudinal penetrations were about 40 times the average radial and tangential penetrations.

DOUGLAS FIR (PSEUDOTSUGA TAXIFOLIA).

The growth rings of Douglas fir were variable in width. The proportion of summerwood varied from almost nothing to nearly half of the growth ring. The spring tracheids were large and thin-walled. Resin cells were few and were scattered on the outer face of the summerwood. The resin passages were

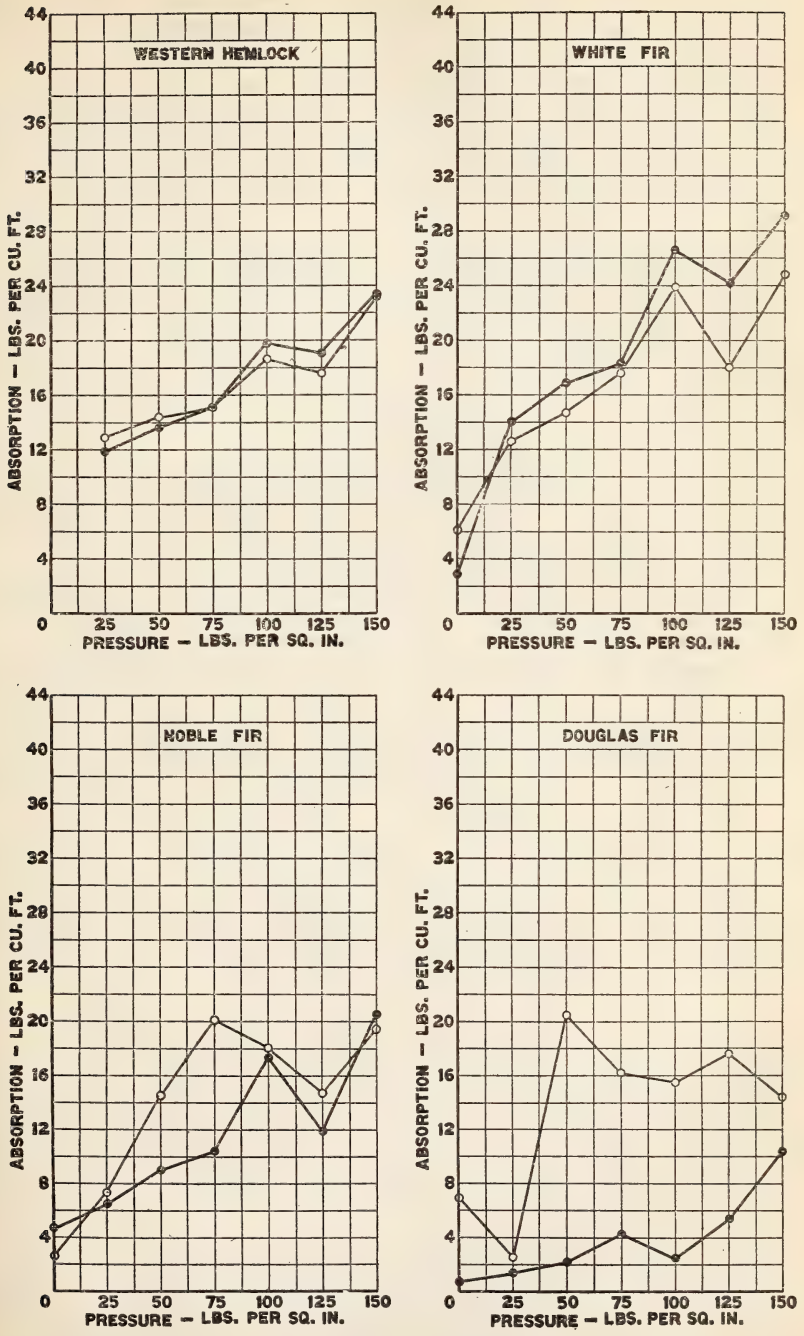
WESTERN HEMLOCK
WHITE FIR
NOBLE FIR
DOUGLAS FIR
ABSORPTION — LBS. PER CU. FT.
PRESSURE — LBS. PER SQ. IN.
0 4 8 12 16 20 24 28 32 36 40 44
0 25 50 75 100 125 150
● HEARTWOOD
○ SAPWOOD

FIG. 6.—Absorption in the heartwood and sapwood of western hemlock, white fir, noble fir, and Douglas fir.

small, few, widely scattered and occurred chiefly in the summerwood; at frequent intervals they were partially obstructed by constrictions.

The average oven-dry weight per cubic foot of four heart specimens was 27.5 pounds, and of five sap specimens 27.7 pounds.

This species contained "fusiform rays"; that is, rays traversed by resin canals, these being smaller than the longitudinal ducts. The ray ducts frequently crossed the longitudinal ones at right angles, thereby forming junctions. This offered the possibility of a deep radial penetration through the radial ducts.

The penetration, especially in the sapwood, took place much more easily in the summerwood than in the springwood. Maximum penetrations took place along the resin ducts, chiefly in the summerwood; in the springwood the ducts were sometimes treated while the surrounding tracheids were not. The springwood was always treated near the point of pressure. In the heartwood both the springwood and summerwood were treated, sometimes equally but usually more heavily in the latter. The sapwood was easily treated, both radially and longitudinally along the two sets of ducts.

The character of penetration in the cylinder treatments was similar to that in the penetrance specimens. The summerwood was much the easier to treat, but the springwood was penetrated by prolonged application of pressure. In some cases springwood resin ducts were found that were not penetrated, whereas the adjacent summerwood was penetrated.

In this species there was a very great difference between penetrations and absorptions in the heartwood and in the sapwood. The former appeared to be almost impenetrable, while the latter was easily treated. This can be explained partially by the larger quantity and less soluble condition of the resin in the canals of the heartwood. In sapwood the radial ducts had a very great influence on penetrations, and it seems probable that this would be the case in the heartwood also for long-continued treatments. There is also a great difference between heartwood and sapwood in the penetrability of the nonresinous structure. Such penetrability is directly affected by the penetrability of the ducts themselves, since creosote in the latter quickly become saturated with resin which must escape to the surrounding wood before penetration can continue.

In heartwood the ratio of longitudinal to radial and tangential penetrations was about 10 or 12 to 1. In sapwood longitudinal penetration was about 12 times radial and 100 times the tangential penetrations.

SITKA SPRUCE (PICEA SITCHENSIS).

The growth rings of Sitka spruce were broad with summerwood equal to or exceeding the springwood. Resin cells were wholly wanting. Resin passages were few, small, and had thick-walled epithelium cells; they were well developed but frequently constricted. Tyloses were sometimes present in the resin canals. The canals in the fusiform rays had also thick-walled epithelium cells. The resin ducts running radially and longitudinally frequently intersected each other.

The average oven-dry weight per cubic foot of seven heart specimens was 19.2 pounds, and of four sap specimens 18.1 pounds.

While the heartwood of this species contained both radial and longitudinal ducts, they were not sufficiently numerous to have much influence on penetration. When present in the springwood the ducts were usually treated, but the oil did not spread to the surrounding structure. Penetration took place very rapidly in the summerwood, which treated almost as easily as the resin

ducts themselves. Springwood was difficult to penetrate but was sometimes treated, especially in the zone where pressure was applied.

In the sapwood, resin ducts occurred frequently that were not well penetrated, while the summerwood band, a few tracheids distant, was heavily treated. The penetration appeared to follow first the very last-formed summerwood tracheids of each year's growth. Later the second and third rows of tracheids were penetrated and finally the entire summerwood band. Still later slight penetration occurred in some of the springwood tracheids, but this was comparatively rare.

In the medullary rays neither the intermediate cells nor the ray parenchyma were treated. The upper and lower ray cells, however, were very frequently penetrated from the longitudinal summerwood tracheids, and these ray cells extended through the longitudinal tracheids of the springwood without in any way penetrating them. This whole phenomenon was not noted in any of the species previously discussed.

The cylinder-treated wood was penetrated in much the same manner as the pieces treated in the penetrance apparatus. All summerwood was well treated, and in the sapwood a considerable amount also of springwood.

This wood, in common with most of the species previously discussed, becomes discolored in the springwood several weeks after treatment. On close examination it was found that most of the discoloration was localized in the bordered pits. It is not evident from present knowledge how this could be confined to the pits without the remainder of the tracheids also becoming discolored.

Resin ducts were not an important factor in the treatment of this species. The summerwood was penetrated very rapidly. The sapwood absorbed more oil than the heartwood, chiefly because the former was more heavily treated in the springwood.

The ratio of average longitudinal to average radial or tangential penetration can not be determined because the specimens were completely penetrated longitudinally, but it was at least 120 times as great.

WHITE SPRUCE (PICEA CANADENSIS).

The growth rings of white spruce were broad; the summerwood was about one-fourth the width of the springwood. Resin cells were never present. The resin passages were few, large, and sometimes contained tyloses. The ducts of the fusiform rays were surrounded by thick-walled epithelial cells.

The average oven-dry weight of five heart specimens was 24 pounds per cubic foot.

The penetrance tests were made on heartwood only. The penetration took place most quickly in the last-formed summer tracheids of the various growth rings, and in most cases the summerwood as a whole was treated more quickly than springwood. Near the point of pressure the springwood was partially treated. Resin ducts in the specimens were so infrequent that they had little effect upon penetration. Ray ducts were difficult to treat and appeared to aid little in radial penetrations.

The cylinder-treated sticks were penetrated similarly to those treated in the penetrance apparatus. Resin ducts when present were usually treated, but apparently they aided very little in the penetration of the tracheids surrounding them. Medullary ray tracheids were occasionally treated, but the penetration was limited and took place with difficulty. The summerwood was usually treated to the center of the stick. Often, however, zones occurred covering several growth rings in which the summerwood was not treated. When the summerwood failed to be penetrated the springwood was not treated. In

some growth rings the springwood was treated to the center, but never as heavily as the summerwood. The treatment was, as a rule, not at all uniform, and considerable resistance was offered to penetration. While sapwood was more penetrable than heartwood, it was, nevertheless, very difficult to treat. The longitudinal penetration was from 35 to 40 times greater than the radial or tangential penetrations.

ENGELMANN SPRUCE (PICEA ENGELMANNI).

In Engelmann spruce the growth rings were broad; the summerwood was open, and one-third to one-half the width of the springwood. Resin cells are never present. The resin passages were large but few, and did not contain tyloses. The fusiform rays contained large radial ducts surrounded by thick-walled epithelial cells.

The average oven-dry weight per cubic foot of six heart specimens was 24.7 pounds, and of five sap specimens 25.9 pounds.

In the heartwood the penetration was chiefly in the summerwood, but a few springwood tracheids were treated near the point of pressure. Resin ducts seemed to be treated with difficulty and did not appear to assist greatly in the penetration. The rays were frequently treated, whether containing resin canals or not. The penetration of the rays most frequently extended over from one to three growth rings and seemed to start from summerwood bands.

Penetration in the sapwood seemed to be chiefly in the resin ducts. The summerwood bands and medullary rays were also treated, but penetration here took place much more slowly than through the resin ducts. Complete longitudinal and radial penetration occurred through the ducts only.

The cylinder tests showed that in heartwood the summerwood bands were all treated to the center of the stick. Resin ducts were sometimes treated, sometimes not. Most of the medullary rays were penetrated. In the sapwood the summerwood was treated as in the heartwood, and in places the springwood was equally well treated. Usually, however, the springwood was only partially treated, as was indicated by its golden-brown color; the treated summerwood was nearly black.

Radial penetration in this species seemed to be due largely to the rays. Apparently, creosote passed from the summerwood to the rays and thence to the next summerwood band, leaving the intervening springwood untreated. Resin ducts were very important factors in the sapwood penetration, but not in the heartwood. The sapwood treated almost instantly and absorbed more oil than the heartwood which was very difficult to penetrate. This difference was one existing chiefly in the springwood of the heart and of the sap respectively. In the latter the springwood was, as a rule, very heavily treated, but not so in the former.

The longitudinal penetration averaged about four times the radial in heartwood and 20 times the radial in sapwood. It was about 50 times the tangential penetrations in both heart and sap.

WESTERN LARCH (LARIX OCCIDENTALIS).

In the western larch specimens the summerwood was equal to about one-half the width of the springwood. The spring tracheids were large and very thin-walled. Resin cells were scattered on the outer face of the summerwood. Resin passages were large, not numerous, without tyloses, and surrounded by thick-walled epithelial cells. The radial canals were large and not very numerous.

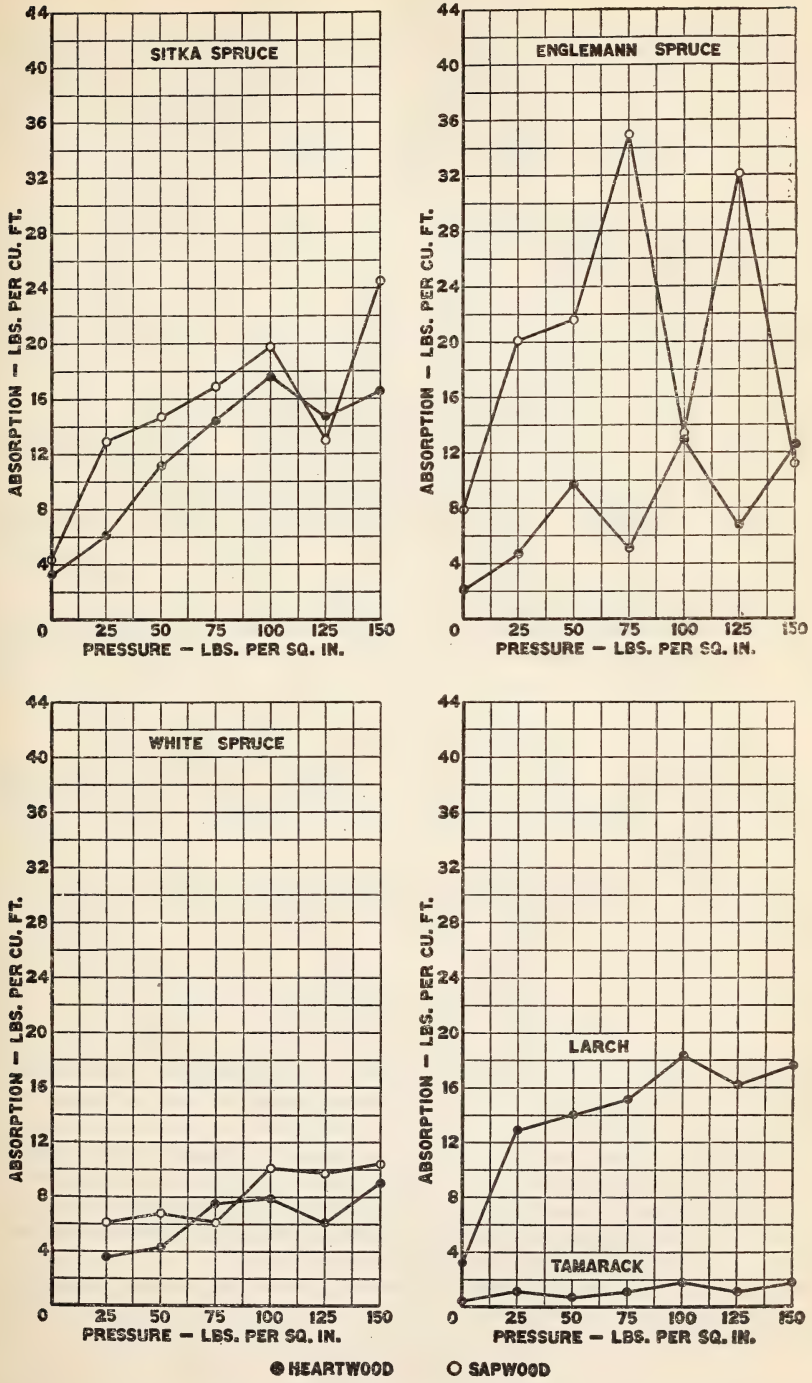
SITKA SPRUCE
ENGLEMANN SPRUCE
WHITE SPRUCE
LARCH
TAMARACK
ABSORPTION — LBS. PER CU. FT.
PRESSURE — LBS. PER SQ. IN.
0 25 50 75 100 125 150
0 4 8 12 16 20 24 28 32 36 40 44
● HEARTWOOD ○ SAPWOOD

FIG. 7.—Absorption in the heartwood and sapwood of Sitka spruce, Engelmann spruce, white spruce, larch, and tamarack.

The average oven-dry weight per cubic foot of six heart specimens was 30.5 pounds.

Heartwood only of western larch was tested, as the sapwood is so thin that suitable pieces were not obtainable. The resin ducts were comparatively easy to penetrate, and isolated ones outside of the zone of longitudinal treatment were very frequently penetrated through intersecting radial ducts. Certain treated resin canals were closely examined and showed that:

1. Where fusiform rays crossed summerwood bands the latter were not treated.

2. The fusiform rays frequently intersected treated longitudinal ducts and usually contained creosote.

3. The summerwood on each side of longitudinal resin ducts was treated tangentially from one-eighth to one-fourth inch.

4. Resin and creosote appeared to be forced away from the resin canal into summerwood, but not often into springwood.

The summerwood was completely penetrated in most of the pieces, while, as a rule, the springwood was penetrated longitudinally about 1 inch only.

Cylinder treatments also showed that summerwood was much more penetrable than springwood. The relatively greater ease of penetration was probably due to the resin ducts, as in every case the greatest penetrations were found to be in the zone of a resin duct. Even without pressure the oil frequently penetrated the ducts longitudinally as much as 6 inches.

In heavily treated portions both springwood and summerwood were treated, but the latter much more heavily than the former.

It is known from other tests that the sapwood of this species is very easily treated, and may be completely penetrated in both springwood and summerwood.

TAMARACK (LARIX LARICINA).

The summerwood of tamarack was from one-fourth to one-half the width of the springwood. Resin cells were few, and widely scattering on the outer face of the summerwood. Resin passages were large and devoid of tyloses, and ran in radial and longitudinal directions.

The average oven-dry weight of six heart specimens was 32.5 pounds per cubic foot. Only heartwood specimens were treated as the sapwood was too thin to cut test specimens.

Tamarack offered great resistance to penetration. While similar to western larch in its microscopic structure, it was very different in its resistance to treatment. Most of the resin ducts were impenetrable under the conditions of the test. Longitudinally penetration occurred in 30 to 45 minutes, but only in a few isolated ducts, and then it did not spread to the surrounding cells, except near the point of pressure. The summerwood seemed to offer as much resistance as did the springwood.

Certain observations were made on treated sapwood of tamarack, which were aside from the regular experiments. These observations showed that the sapwood was very easy to penetrate. Both the springwood and summerwood (in the sap) were saturated with oil in a moderate treatment; the summerwood usually seemed to have the heavier absorption.

The average longitudinal penetration was 22 times the average radial and tangential penetrations.

LODGEPOLE PINE (PINUS MURRAYANA).

The growth rings of lodgepole pine were broad, with the summerwood about one-fourth the width of the springwood. The transition from one to the other was gradual. Resin cells were entirely absent. Resin canals were rather small; numerous, and mostly in the summerwood; radial ducts were few.

The average oven-dry weight per cubic foot of six heart specimens was 23.4 pounds, and of six sap specimens, 22.9 pounds.

The heartwood of lodgepole pine greatly resisted treatment, and resisted longitudinal penetration nearly as much as radial. What penetration occurred took place through the longitudinal and radial resin ducts. From these the summerwood was more or less treated, and occasionally a medullary ray (not fusiform) was found to be penetrated. In the tracheids, even when a pressure of 90 pounds was applied for one hour (piece 166), the penetration longitudinally was not deeper than the length of three cells, and tangentially not over six cells, and then very light. The treatment seemed to take place chiefly through the radial ducts, the oil passing to the longitudinal ducts wherever the two intersected.

In the cylinder most of the resin ducts appeared to be treated, and one split section showed creosote in the center of the piece. Cells surrounding the treated ducts in the summerwood appeared to be treated farther than equivalent cells in the springwood.

The sapwood was variable in its penetrability. Two of the pieces were penetrated radially in 30 to 45 seconds, the oil flowing copiously from the tangential surfaces almost as soon as pressure was applied, while the other piece required 20 minutes to be penetrated radially. The nonresin structure was very easily treated in both springwood and summerwood, but more quickly in the latter. The medullary ray cells also were usually treated.

In the cylinder the sapwood treated very easily, and even in the light treatments both springwood and summerwood were saturated. So easily was the sapwood treated that no difference in absorption was evident between pieces soaked in hot oil (run 7) and others treated at a pressure of 150 pounds (run 6).

It is evident that in a thorough treatment of large timbers of this species the sapwood will be completely treated while the heartwood will be penetrated radially from 1 to 2 inches. The average longitudinal penetration was about one and one-half times the radial; the tangential penetration could not be determined, but was probably negligible.

JACK PINE (PINUS DIVARICATA).

The summerwood of jack pine was dense, and about one-third the width of the springwood. Resin canals were small, numerous, chiefly in the summerwood, and contained tyloses. Radial ducts were not numerous.

The average oven-dry weight per cubic foot of five heart specimens was 25.4 pounds.

In the heartwood of jack pine longitudinal penetration took place first through the resin ducts, from which the oil passed into the surrounding cells. Summerwood was penetrated much more easily than springwood, and usually all summerwood bands were treated. The springwood was not, however, very difficult to penetrate, as this also contained many resin ducts. Treatment was comparatively rapid in the radial resin ducts; from these the penetration was diverted to the longitudinal ducts wherever the two sets crossed.

In the cylinder sapwood was treated first in the summerwood. The springwood also treated very quickly, and in the heavier treatments both springwood

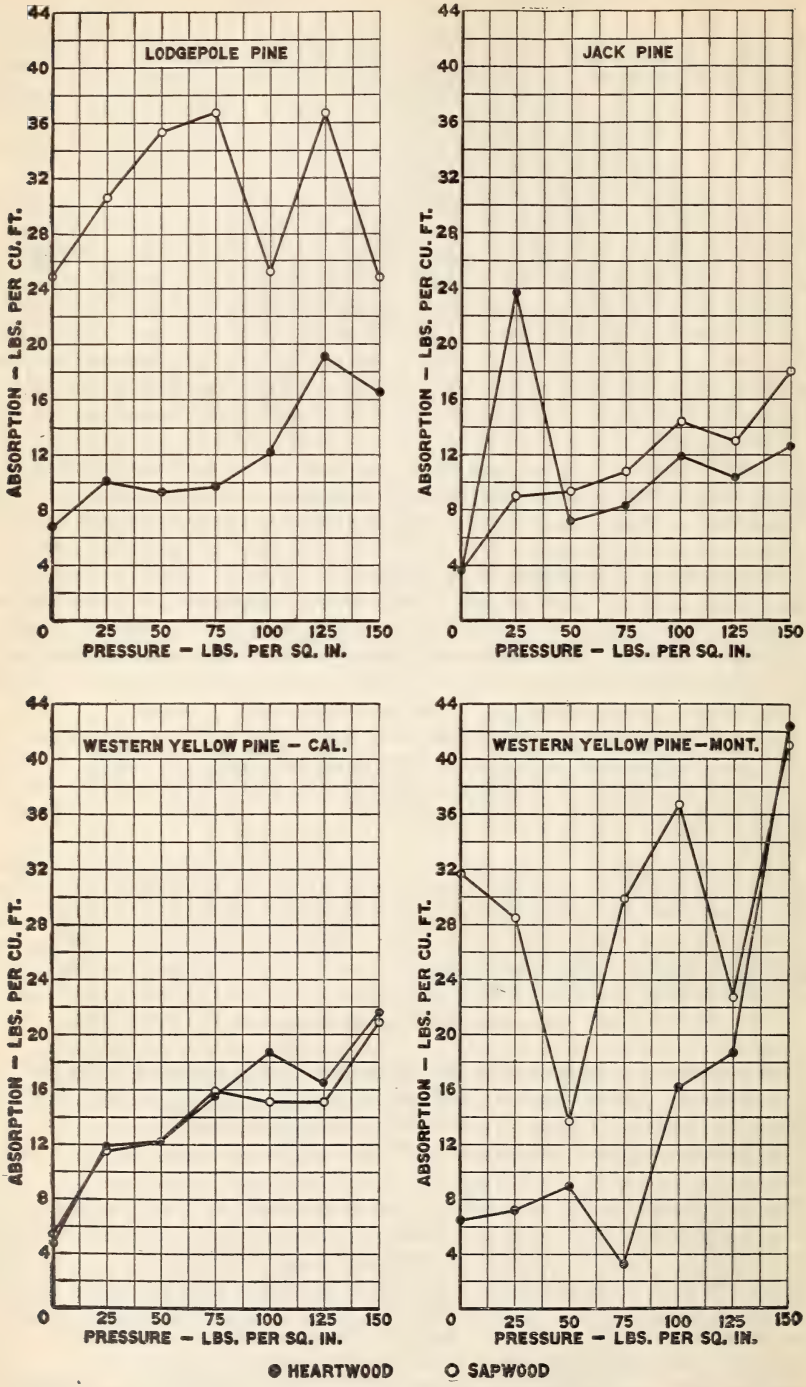
LODGEPOLE PINE
JACK PINE
WESTERN YELLOW PINE — CAL.
WESTERN YELLOW PINE—MONT.
ABSORPTION — LBS. PER CU. FT.
PRESSURE — LBS. PER SQ. IN.
0 4 8 12 16 20 24 28 32 36 40 44
0 25 50 75 100 125 150
● HEARTWOOD
○ SAPWOOD

FIG. 8.—Absorption in the heartwood and sapwood of lodgepole pine, jack pine, and western yellow pine.

and summerwood were saturated, resulting in very heavy absorptions. These are not evident in the absorption data, because the sapwood specimens really contained at least 50 per cent of heartwood. This condition was unavoidable because of the very thin sapwood that was available.

Radial penetration was an important factor in this species. In the heartwood it averaged from one-eighth to one-fourth as great as the longitudinal penetration; the tangential was only about one-eightieth of the longitudinal.

WESTERN YELLOW PINE (PINUS PONDEROSA).

The summerwood of western yellow pine was variable, dense, and was from one-third to one-half the width of the springwood. The spring tracheids were rather thick-walled. Resin passages were of medium size, numerous, and located chiefly in the summerwood. Radial ducts were also numerous.

The average oven-dry weight per cubic foot of six heart specimens from California was 25 pounds, and of six sap specimens 23 pounds; of six heart specimens from Montana 25.4 pounds, and of five sap specimens 27.4 pounds.

In the heartwood of the western yellow-pine specimens from California the summerwood treated more easily than the springwood. Usually the entire summerwood band was penetrated, and often many of the springwood tracheids were heavily treated. The longitudinal and radial ducts were the channels through which the penetration first took place, and from these it passed into the summerwood. When springwood was treated, the oil seemed to come from radial ducts and usually did not penetrate far from them. In the specimens from Montana the summerwood treated first, as in the California specimens, but the outer summer tracheids had the heaviest absorptions and were treated for the greatest distances. The springwood was untreated except for isolated tracheids which were penetrated from the ray ducts.

In the sapwood of the California specimens penetration took place very rapidly in the resin ducts, but throughout the tracheids treatment required as much time as in the heartwood; and on microscopical examination both heartwood and sapwood were found to have the same appearance. In the radial ducts of the specimens from Montana sapwood penetration was much greater than in those from California. Immediately after pressure was applied oil flowed from these ducts, and the entire sapwood, both springwood and summerwood, was heavily treated within a few seconds.

In the cylinder-treated sticks of the California tree both heartwood and sapwood had the same appearance, and while in both the summerwood appeared to have the heavier absorptions, the springwood also was very heavily discolored. The Montana tree, however, was not penetrated quickly in the heart springwood, except in the case of certain pieces (Nos. 41–46) which treated like the sapwood. In these specimens the summerwood was treated throughout. In case of the lighter absorptions the springwood was practically untreated, but as the absorptions increased the proportion of springwood treated also increased.

In the California specimens longitudinal penetration averaged about 8 times the radial and 30 times the tangential penetration. In the Montana specimens the longitudinal penetration averaged about 4 times the radial and 50 times the tangential penetrations.

SPRUCE PINE (PINUS GLABRA).

The spruce-pine specimens were of extremely rapid growth. The summerwood was about one-half the width of the springwood. Resin ducts were very numerous and large, especially in the summerwood. Radial ducts were few. The sapwood was much lighter in weight than the heartwood.

The average oven-dry weight per cubic foot of seven heart specimens was 32.2 pounds, and of six sap specimens 26 pounds.

Two heartwood pieces of spruce pine (Nos. 225 and 240) treated like the sapwood. These pieces became saturated with oil almost as soon as pressure was applied, and on splitting both springwood and summerwood were found to be uniformly discolored with creosote. Examined microscopically, no difference appeared between these pieces and other heartwood directly adjacent that was very resistant to penetration.

Three heartwood pieces were found, however, that resisted penetration in the manner usually noted in the heartwood of pine. These pieces of spruce pine were, in fact, among the most impenetrable in the entire series of species tested. They were penetrated in the summerwood somewhat more quickly than in the springwood, and microscopic examination showed that the summerwood plainly was the most heavily treated portion. The medullary rays were frequently lightly treated. While radial and longitudinal ducts were often filled with what appeared to be a mixture of resin and creosote, they did not seem to aid materially in the penetration. The presence of a bright yellow substance in many of the tracheids of the heartwood, especially near resin ducts and in the springwood, seemed to indicate that resin had been forced from the ducts into the surrounding tracheids.

In the sapwood, while the summerwood treated more easily than the springwood, yet the latter was also very penetrable. Microscopic examination showed the summerwood to be saturated with oil and the springwood deeply colored. The medullary rays were usually treated. The resin ducts of the sapwood were usually heavily treated and seemed to be responsible for the quick penetrance of sapwood.

In the cylinder the heartwood piece treated in the nonpressure run showed that the greatest penetrance took place in the summerwood resin ducts. The springwood was treated for ½ to 1 inch, while summerwood was treated (around resin ducts only) from 1 to 6 inches. In some of the pressure treatments the springwood also was found to be heavily treated. The absorption, as indicated by the color of the treated sticks was very uneven.

The sapwood was very heavily treated in both springwood and summerwood; the latter, however, seemed to have taken the oil more quickly. Increasing the pressure did not seem to greatly increase the absorption in the sapwood, because it could be saturated without pressure. In general, spruce pine was extremely erratic in its penetrability and in its absorption of creosote. Some portions of heartwood were completely saturated with oil, while others directly adjacent were almost impenetrable. The average longitudinal penetration in heartwood was about 5 times the average radial and 16 times the average tangential penetrations.

LONGLEAF PINE (PINUS PALUSTRIS).

The growth rings of longleaf pine were usually narrow, with very dense summerwood. Resin cells were never present. Resin passages were numerous and large, chiefly in the summerwood, and contained tyloses. Ray ducts were few.

The average oven-dry weight in pounds per cubic foot of six heart specimens was 35.3 pounds, and of six sap specimens 22.8 pounds.[1]

In the heartwood while the summerwood was more penetrable than the springwood the latter was also easily treated. Both longitudinal and ray

[1] It should be noted that the dry weight of the sapwood was only two-thirds that of the heartwood. This was due to much thinner summerwood bands in the sapwood.

ducts were usually filled with creosote, from which isolated spring tracheids were frequently treated.

In the sapwood the resin ducts were always thoroughly penetrated by creosote. The summerwood was very heavily treated, and the springwood was evenly stained to a color much darker than the untreated wood, although creosote was not actually visible as such. Medullary rays were treated to about the same extent as the springwood.

In the cylinder the deepest penetrations and heaviest absorptions of the heart were in the summerwood. Here the treated wood was usually very dark, except in the farthest limits of summerwood penetration, where the color shaded so gradually to that of the natural wood that no line between treated and untreated wood could be detected. While more difficult to treat than summerwood, the springwood did not offer great resistance to penetration. Certain zones of springwood were often found that seemed to be filled with an oil much lighter in color than that in the adjacent summerwood. This may have been resin or creosote in which resin was dissolved. These zones were located between heavily treated summerwood bands; they were usually very close to resin ducts and were found only in the more heavily treated sections of the wood.

In sapwood the summerwood was in every case very heavily treated. Springwood was erratic in its absorption, some portions being black, others being only slightly discolored.

In general longleaf pine was found to be erratic in its penetrance and absorption of creosote. The sapwood was very easily penetrated and absorbed much oil without the aid of pressure. Merely dipping the sapwood was sufficient to penetrate it completely and to secure absorptions almost as heavy as those under the heaviest pressures. In heartwood the average longitudinal penetration was about 26 times the average radial and 100 times the average tangential penetrations.

SHORTLEAF PINE (PINUS ECHINATA).

The growth rings of shortleaf pine were broad, with summerwood which often exceeded the springwood in thickness. Resin cells were never present. Resin passages were large, numerous, scattering, and contained tyloses. Ray ducts were also numerous.

The average oven-dry weight per cubic foot of five heart specimens was 39 pounds, and of the five sap specimens, 31.8 pounds.

In the heart the summerwood was treated more thoroughly than the springwood, but penetration even in the summerwood was very difficult and took place only around the resin ducts. Very frequently penetration failed to occur in all of the summerwood tracheids, and often it occurred in only three or four of them, and these separated from one another. These tracheids were apparently reached from the medullary rays, which, in turn, were reached either from other longitudinal tracheids or from resin ducts. The medullary rays were frequently penetrated in one or more tracheids, and they may play an important part in the treatment of this species.

The heartwood in this species was one of the most impenetrable of the heartwood in any of the species tested; its longitudinal penetration was only 2.75 inches. In absorption shortleaf compares very favorably with other southern pines. All of these species were variable in the heartwood, and it is probable that if sufficient tests were made the penetration of shortleaf pine would show results similar to longleaf pine.

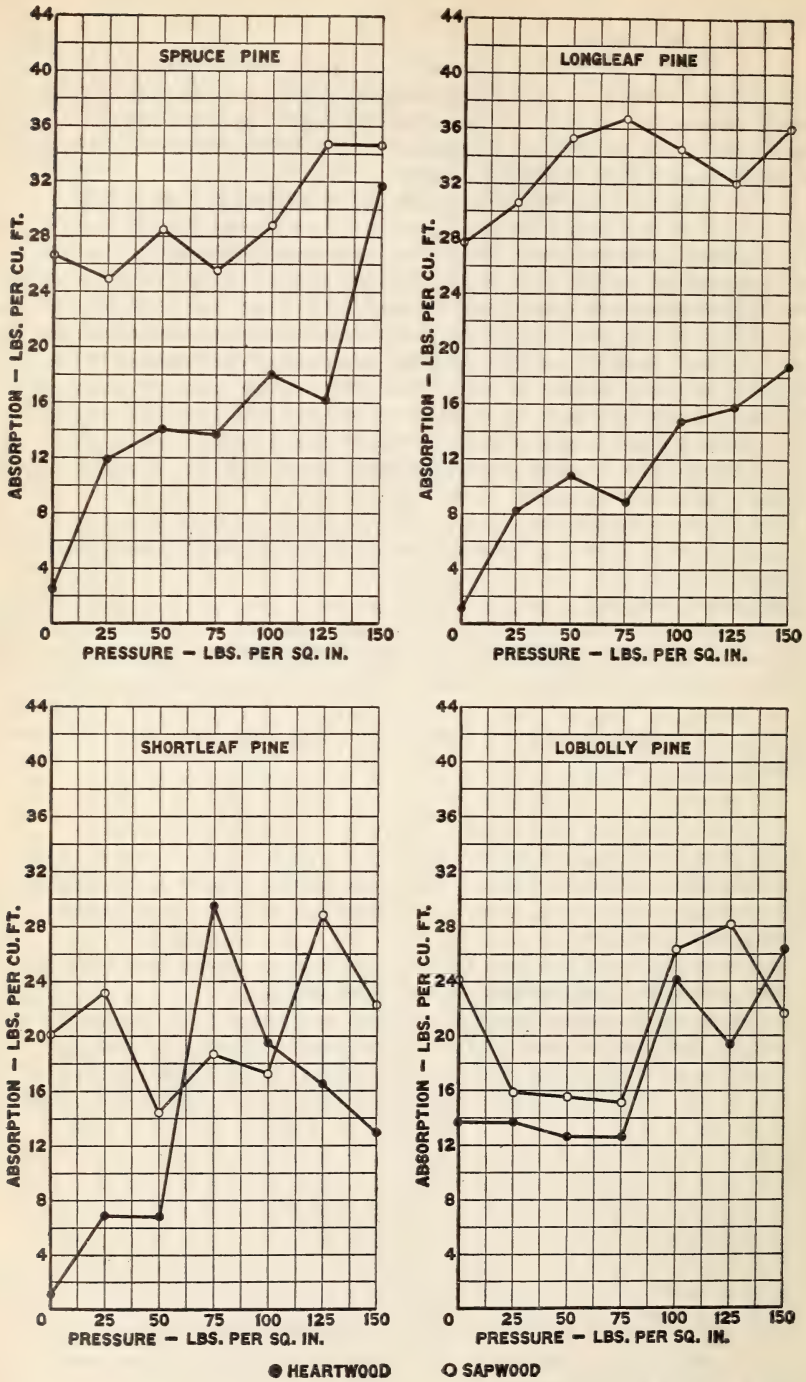
SPRUCE PINE
LONGLEAF PINE
SHORTLEAF PINE
LOBLOLLY PINE
ABSORPTION — LBS. PER CU. FT.
PRESSURE — LBS. PER SQ. IN.
0 4 8 12 16 20 24 28 32 36 40 44
0 25 50 75 100 125 150
● HEARTWOOD
○ SAPWOOD

FIG. 9.—Absorption in the heartwood and sapwood of spruce pine, longleaf pine, shortleaf pine, and loblolly pine.

The sapwood was extremely easy to treat. The oil penetrated radially in from 5 to 10 seconds and ran from the tangential surfaces in streams. After removal the pieces were found to be saturated with creosote.

The heartwood pieces treated in the cylinder appeared to have been treated more thoroughly than those in the penetrance apparatus. Penetration took place probably through the radial ducts, but it was not accomplished without the use of pressure. The piece in the nonpressure run was treated in the summerwood only, and then only from 1 to 2 inches deep, longitudinally. The summerwood was in most cases more heavily treated than the springwood, but the latter was frequently treated at the ends of the tracheids near the rays, where masses of dark-colored oil would collect. In the sap the summerwood was in all cases heavily treated. The springwood treated erratically in some places as heavily as summerwood, in others only lightly. In this respect the species resembled longleaf pine. Much of the springwood contained golden-yellow oil as distinguished from the brownish-black oil filling the summerwood.

Except for the greater resistance, the general character of the penetrations in this species was similar to that in longleaf pine. The average longitudinal penetration was about 8 times the radial and 55 times the average tangential penetrations.

LOBLOLLY PINE (PINUS TÆDA).

In the specimens of loblolly pine the growth was very rapid, some of the rings being over one-half inch wide; the springwood usually was somewhat wider than the summerwood. Resin passages were numerous, very large, chiefly in the summerwood, and contained tyloses. Radial ducts were numerous. The length of tracheids varied from 40 to 100 times their width.

The average oven-dry weight per cubic foot of four heart specimens was 33.1 pounds, and of seven sap specimens 32.1 pounds.

In the heart the summerwood was more easily penetrated than the springwood, and resin ducts were an important factor in the penetrations. Springwood ducts were not treated as far as summerwood ducts, although the springwood itself was quite easily penetrated, and in heavily treated portions the absorption appeared to be nearly as heavy as in the summerwood. The medullary rays were treated about as heavily as the springwood.

The sapwood was penetrated very rapidly, and within a few seconds after applying pressure the oil ran from the tangential surfaces in streams through the resin ducts. The pieces were also penetrated longitudinally within a few seconds. The summerwood was in all cases heavily treated, but the springwood only partially. Had the latter been longer under pressure, however, it also would probably have been fully treated. Creosote collected in the rays and in the ends of the spring tracheids which frequently also were treated for their entire length. Most spring tracheids appeared to be stained when not filled with oil.

In the cylinder most heartwood pieces treated rapidly in both springwood and summerwood. In the piece treated without pressure some springwood bands were found where the resin ducts were penetrated, although the surrounding springwood remained untreated. Many of the medullary rays were treated lightly, and all of the ray ducts appeared to be filled with oil.

In sapwood both springwood and summerwood were heavily treated. The summerwood, however, appeared to be more heavily treated than the springwood. All of the latter was stained, and there was evidence of the presence of oil much lighter in color than that in the summerwood. Many spring tracheids were heavily treated, especially at the ends near the medullary rays.

In general, this species was very easy to penetrate in both heart and sap wood. There was no great differences between the appearance of this species after treatment and that of longleaf and shortleaf pines.

The average longitudinal penetration in the heartwood was about 20 times the average radial and 80 times the average tangential penetration.

TABLE 2.—*Order of species in respect to longitudinal and radial penetrations and absorptions.*

Species.	Character of wood.	Penetrance tests.					Impregnation tests, absorption per cubic foot.	Order of species in respect to—			Average dry weight per cubic foot.
		Number of specimens in average.	Average time of treatment.	Time required to penetrate 12 inches.	Average longitudinal penetration.	Average radial penetration.		Longitudinal penetration.	Radial penetration.	Absorption.	
			Min.	*Min.*	*In.*	*In.*	*Lbs.*				*Lbs.*
Douglas fir	Heart.	3	70	.....	0.57	0.05	4.38	1	2	4	32.5
Tamarack	...do...	3	70	35	.87	.04	1.26	2	1	1	33.5
Lodgepole pine	...do...	3	52	.....	.98	.63	12.84	3	25	12	25.1
Spruce pine	...do...	3	70	.....	1.65	.30	17.58	4	20	26	34.4
Alpine fir	...do...	3	70	.....	1.73	.11	3.66	5	7	2	25.2
Shortleaf pine	...do...	3	70	.....	[1] 2.75	.35	15.36	6	21	17	39.7
Engelmann spruce	...do...	3	75	.....	2.83	.83	8.64	7	27	7	27.2
Western larch	...do...	3	70	15	3.17	.09	15.72	8	11	18	34.1
White spruce	...do...	3	70	.....	3.27	.09	6.42	9	9	5	25.6
Yew	...do...	3	70	.....	3.42	.08	12.36	10	8	9	38.8
Western yellow pine, Montana	...do...	3	70	.....	4.42	1.25	16.14	11	29	20	25.0
Jack pine	...do...	3	70	.....	4.43	1.27	12.36	12	30	8	28.8
Redwood	...do...	3	77	.....	4.58	.16	18.78	13	16	29	20.5
Alpine fir	Sap...	3	70	.....	5.50	.07	4.14	14	6	3	22.7
Noble fir	Heart.	3	65	14	5.83	.12	12.60	15	14	11	24.1
Douglas fir	Sap...	3	70	20	6.10	.43	14.46	16	23	15	30.9
Eastern hemlock	Heart.	3	70	35	6.67	.07	17.28	17	5	25	23.4
Do	Sap...	2	45	.....	6.75	.05	18.78	18	3	28	20.3
Redwood	...do...	3	70	.....	6.87	.13	21.06	19	15	33	20.2
Western hemlock	Heart.	3	70	30	7.42	.06	17.16	20	4	24	30.8
Western yellow pine, California.	...do...	4	61	48	7.60	.72	16.08	21	26	19	28.9
Western hemlock	Sap...	3	70	30	8.27	.09	17.04	22	10	23	32.0
Loblolly pine	Heart.	3	60	½	8.33	.85	18.12	23	28	27	35.9
White fir	Sap...	3	65	15	9.00	.18	18.96	24	18	30	24.1
Sitka spruce	...do...	3	45	9	9.33	.10	16.98	25	13	22	19.7
Lodgepole pine	...do...	3	21	½ to 40	9.67	([2])	31.56	26	37	38	23.6
Longleaf pine	Heart.	3	70	16	9.83	.38	12.90	27	22	13	39.2
White fir	...do...	3	70	24	10.05	.20	21.54	28	19	34	23.4
Noble fir	Sap...	3	70	3	10.33	.18	16.20	29	17	21	24.8
Western yellow pine, California.	...do...	3	15	10	4.50	[3].54	15.12	30	24	16	29.8
Sitka spruce	Heart.	2	70	23	12.00	.09	13.44	31	12	14	18.5
Spruce pine	Sap...	3	3	5	[4] 12.00	([2])	29.46	32	33	37	30.8
Engelmann spruce	...do...	3	2	½	6.83	.37	22.20	33	31	35	30.9
Shortleaf pine	...do...	3	2	½	[4] 12.00	([2])	20.76	34	32	32	35.3
Longleaf pine	...do...	3	1	1	[4] 12.00	([2])	34.20	35	35	39	25.2
Western yellow pine, Montana.	...do...	3	1½	½	[4] 12.00	([2])	28.74	36	34	36	25.9
Loblolly pine	...do...	3	½	½	[4] 12.00	([2])	20.40	37	36	31	37.3
White spruce	...do...	.....	.....	.....	.....	.....	8.22	.....	.....	6	26.1
Jack pine	...do...	.....	.....	.....	.....	.....	12.42	.....	.....	10	30.7

[1] See discussion on page 33 of Appendix.

[2] Complete. Since the radial penetration of lodgepole, spruce, shortleaf, longleaf, and western yellow (Montana), and loblolly pine was complete in each case, the relative order of these species is not significant.

[3] Treated for 15 minutes only and penetrated same distance as heartwood in an equal time.

[4] Complete.

NOTE.—When penetration was complete it was not more than 12 inches, as the specimens could be penetrated a total distance longitudinally of only 12 inches. Complete radial penetration varied in different specimens. The minimum for complete penetration radially was 1 inch, and the maximum 1.50 inches. This depended upon the direction of the annual rings in reference to the surface of the specimen.

TABLE 3.—*Proposed grouping of species for treatment.*

Class.	Species.	Penetration.		Absorption per cubic foot.
		Longitudinal.	Radial.	
		In.	*In.*	*Pounds.*
I	Alpine fir, heartwood	1.73	0.11	3.66
	Yew, heartwood [1]	3.42	.08	12.36
	Alpine fir, sapwood	5.50	.07	4.14
II	Douglas fir, heartwood	.57	.05	4.38
	Tamarack, heartwood [1]	.87	.04	1.26
	White spruce, heartwood [2]	3.27	.09	6.42
III	Western larch, heartwood	3.17	.09	15.72
	Redwood, heartwood	4.58	.16	18.78
	Noble fir, heartwood	6.07	.12	12.60
	Eastern hemlock, heartwood	6.66	.07	17.28
	Eastern hemlock, sapwood	6.75	.05	18.78
	Redwood, sapwood	6.83	.13	21.06
	Western hemlock, heartwood	7.42	.06	17.16
	Western hemlock, sapwood	8.27	.09	17.04
	White fir, sapwood	9.00	.18	18.96
	Sitka spruce, sapwood	9.33	.10	16.98
	White fir, heartwood	10.05	.20	21.54
	Noble fir, sapwood	10.33	.18	16.20
	Sitka spruce, heartwood	12.00	.09	13.44
IV	Lodgepole pine, heartwood	.98	.63	12.84
	Spruce pine, heartwood	1.65	.30	17.58
	Shortleaf pine, heartwood	2.75	.35	15.36
	Engelmann spruce, heartwood	2.83	.83	8.64
	Western yellow pine, heartwood	4.42	1.25	16.14
	Jack pine, heartwood	4.43	1.27	12.36
	Western yellow pine, California, heartwood	7.60	.72	16.08
	Longleaf pine, heartwood	9.83	.38	12.90
	Loblolly pine, heartwood	8.33	.85	18.12
V	Tamarack, sapwood	Penetration not determined. All except white spruce known to treat very easily.		
	Western larch, sapwood			
	Jack pine, sapwood			
	White spruce, sapwood			
	Western yellow pine, California, sapwood	4.50	0.54	15.12
	Douglas fir, sapwood	6.10	.43	14.46
	Engelmann spruce, sapwood	6.83	.37	22.20
	Lodgepole pine, sapwood	9.67	[3]	31.56
	Spruce pine, sapwood	[3]	[3]	29.46
	Western yellow pine, sapwood	[3]	[3]	28.74
	Longleaf pine, sapwood	[3]	[3]	34.20
	Shortleaf pine, sapwood	[3]	[3]	20.76
	Loblolly pine, sapwood	[3]	[3]	20.40

[1] Sapwood not available for either penetrance or impregnation tests.
[2] Sapwood not available for penetrance tests.
[3] Complete.

TABLE 4.—*Results of penetrance tests on individual pieces.*

YEW—HEARTWOOD.

Piece No.	Moisture.	Average number of rings per inch.	Oven-dry weight per cubic foot.	Total time of treatment.	Average temperature.	Average pressure per square inch.	Time required to penetrate 12 inches.		Penetrations.					
									Longitudinal.		Radial.		Tangential.	
							First end.	Second end.	Average.	Maximum.	Average.	Maximum.	Average.	Maximum.
	Per ct.		*Lbs.*	*Min.*	*°F.*	*Lbs.*	*Min.*	*Min.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
3	10.4	21.0	38.0	30	145	89	(1)	(1)	2.50	5.00	0.08	0.10	0.06	0.08
2	15.3	16.0	35.8	60	145	87	(1)	(1)	3.50	6.60	.10	.10	.06	.08
1	16.6	26.0	40.7	120	145	90	(1)	(1)	4.25	9.20	.06	.10	.06	.10
Average	14.1	21.0	38.2	70	145	89	(1)	(1)	3.42	6.93	.08	.10	.06	.09

[1] Creosote did not penetrate to end of specimens.

TABLE 4.—*Results of penetrance tests on individual pieces*—Continued.

ALPINE FIR—HEARTWOOD.

Piece No.	Moisture.	Average number of rings per inch.	Oven-dry weight per cubic foot.	Total time of treatment.	Average temperature.	Average pressure per square inch.	Time required to penetrate 12 inches.		Penetrations.					
									Longitudinal.		Radial.		Tangential.	
							First end.	Second end.	Average.	Maximum.	Average.	Maximum.	Average.	Maximum.
	Per ct.		*Lbs.*	*Min.*	*° F.*	*Lbs.*	*Min.*	*Min.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
308	11.6	21.8	22.6	30	135	90	(1)	(1)	0.70	4.20	0.10	0.15	0.05	0.10
307	11.9	20.4	22.0	60	143	90	(1)	(1)	2.20	6.60	.08	.10	.08	.10
309	13.2	17.1	20.9	120	143	90	(1)	(1)	2.30	7.40	.15	.20	.10	.12
Average...	12.2	19.8	21.8	70	140	90	(1)	(1)	1.73	6.07	.11	.15	.08	.11

ALPINE FIR—SAPWOOD.

301	12.3	15.0	20.9	30	143	90	(1)	(1)	5.0	5.5	0.05	0.15	0.05	0.10
302	9.7	14.5	22.6	60	133	90	(1)	(1)	6.0	7.0	.10	.10	.15	.30
303	11.6	14.6	22.4	120	152	90	(1)	75	5.5	9.0	.05	.10	.15	.30
Average...	11.2	14.7	22.0	70	143	90	(1)	(1)	5.5	7.2	.07	.12	.12	.23

REDWOOD—HEARTWOOD.

118	13.6	19.3	19.9	60	140	88	(1)	(1)	4.20	10.4	0.20	0.25	0.18	0.25
117	9.5	18.7	20.2	68	130	85	(1)	(1)	3.80	10.9	.15	.18	.15	.30
121	18.1	18.6	19.5	102	136	82	(1)	(1)	5.75	12.0	.13	.16	.10	.32
Average...	13.7	18.9	19.9	77	135	85	(1)	(1)	4.58	11.1	.16	.20	.14	.29

REDWOOD—SAPWOOD.

85	.....	26.2	20.1	31	138	88	(1)	(1)	5.75	12.0	0.14	0.16	0.10	0.35
88	13.2	27.3	27.2	60	142	78	(1)	(1)	9.25	12.0	.11	.13	.09	.11
86	12.7	29.7	28.0	120	140	85	(1)	(1)	5.60	8.1	.13	.15	.09	.16
Average...	13.0	27.7	25.1	70	140	84	(1)	(1)	6.87	10.7	.13	.15	.09	.21

EASTERN HEMLOCK—HEARTWOOD.

256	11.8	35.9	22.20	30	139	88	30	.....	5.50	12.0	0.08	0.10	0.06	0.08
265	10.5	23.6	21.60	60	139	89	30	30	7.50	12.0	.09	.11	.10	.30
259	9.4	25.0	24.70	120	144	86	45	60	7.0	12.0	.05	.10	.10	.35
Average...	10.6	28.2	22.83	70	141	88	.....	.....	6.67	12.0	.07	.10	.09	.24

EASTERN HEMLOCK—SAPWOOD.

251	11.9	24.5	18.40	30	141	89	5	30	8.5	12.0	0.05	0.08	0.10	0.12
254	14.5	31.7	18.60	60	135	87	.....	30	5.0	12.0	.05	.08	.10	.16
Average...	13.2	28.1	18.50	45	138	88	.....	.....	6.75	12.0	.05	.08	.10	.14

WESTERN HEMLOCK—HEARTWOOD.

92	12.6	10.8	25.6	30	142	87	(1)	(1)	8.50	12.0	0.06	0.15	0.09	0.13
95	10.4	12.6	27.9	60	137	88	30	(1)	5.00	12.0	.05	.10	.05	.10
91	7.8	13.1	27.9	120	133	85	30	(1)	8.75	12.0	.06	.15	.10	.15
Average...	10.3	12.2	27.1	70	137	87	.....	.....	7.42	12. 0	.06	.13	.08	.13

[1] Creosote did not penetrate to end of specimens.

TABLE 4.—*Results of penetrance tests on individual pieces*—Continued.

WESTERN HEMLOCK—SAPWOOD.

Piece No.	Moisture.	Average number of rings per inch.	Oven-dry weight per cubic foot.	Total time of treatment.	Average temperature.	Average pressure per square inch.	Time required to penetrate 12 inches.		Penetrations.					
									Longitudinal.		Radial.		Tangential.	
							First end.	Second end.	Average.	Maximum.	Average.	Maximum.	Average.	Maximum.
	Perct.		*Lbs.*	*Min.*	*°F.*	*Lbs.*	*Min.*	*Min.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
89	8.3	20.5	28.6	30	124	84	30	(1)	8.50	12.0	0.06	0.08	0.11	0.20
86	13.1	26.4	28.0	60	138	83	(1)	(1)	8.30	12.0	.08	.12	.12	.32
90	13.2	22.0	27.5	120	135	80	30	(1)	8.00	12.0	.12	.15	.13	.30
Average	11.5	23.0	28.0	70	132	82	.....	.....	8.27	12.0	.09	.12	.12	.27

ENGLEMANN SPRUCE—HEARTWOOD.

172	9.4	24.5	23.82	45	128	89	(1)	(1)	2.50	3.50	0.50	1.10	0.05	0.05
178	10.5	12.2	25.28	60	151	90	(1)	(1)	4.0	6.50	1.00	1.30	.05	.05
157	8.0	10.9	25.89	120	151	88	(1)	(1)	2.0	6.0	1.00	1.00	.08	.08
Average	9.3	15.9	25.00	75	143	89	.....	.....	2.83	5.33	.83	1.13	.06	0.6

ENGLEMANN SPRUCE—SAPWOOD.

134	7.3	44.4	26.85	1	115	89	½	½	6.0	12.0	0.50	0.80	0.30	0.50
148	13.6	21.8	26.88	2	118	89	1	1	2.50	12.0	.30	.90	.08	.10
190	21.0	42.0	25.60	2	120	89	Immediately.		12.0	12.0	.30	.60–1.6	.05	.05
Average	14.0	36.1	26.44	2	118	89	.....	.....	6.8	12.0	.36	.98	.14	.22

WESTERN LARCH—HEARTWOOD.

226	10.3	55.0	30.78	30	141	76	(1)	(1)	1.00	3.4	0.06	0.30	0.07	0.10
211	11.2	58.0	29.13	60	151	89	15	30	5.00	12.0	.10	.80	.12	.30
210	8.9	60.0	30.70	120	140	80	15	30	3.50	12.0	.10	.10	.12	.30
Average	10.1	58	30.20	70	144	82	.....	.....	3.17	9.1	.09	.40	.10	.23

TAMARACK—HEARTWOOD.

312	12.3	13.6	32.1	30	143	87	30	30	0.50	12.0	0.02	0.05	0.02	0.05
313	12.1	14.0	30.4	60	134	90	45	30	1.50	12.0	.05	.10	.05	.10
311	12.1	14.4	30.4	120	139	86	30	30	.60	12.0	.05	.10	.05	.10
Average	12.2	14.0	31.0	70	139	88	.....	.....	.87	12.0	.04	.08	.04	.08

LODGEPOLE PINE—HEARTWOOD.

167	13.7	5.9	22.62	35	134	87	(1)	(1)	0.20	2.00	1.00	1.20	(2)	(2)
138	12.5	5.9	22.43	60	133	90	(1)	(1)	.50	2.50	.30	1.00	(2)	(2)
166	9.7	6.4	23.02	60	148	90	(1)	(1)	2.25	4.00	.60	1.20	(2)	(2)
Average	12.0	6.1	22.69	52	138	89	.....	.....	.98	2.83	.63	1.13	.....	.....

[1] Creosote did not penetrate to end of specimens. [2] Could not be determined.

TABLE 4.—*Results of penetrance tests on individual pieces*—Continued.

LODGEPOLE PINE—SAPWOOD.

Piece No.	Moisture.	Average number of rings per inch.	Oven-dry weight per cubic foot.	Total time of treatment.	Average temperature.	Average pressure per square inch.	Time required to penetrate 12 inches.		Penetrations.					
									Longitudinal.		Radial.		Tangential.	
							First end.	Second end.	Average.	Maximum.	Average.	Maximum.	Average.	Maximum.
	Perct.		*Lbs.*	*Min.*	*°F.*	*Lbs.*	*Min.*	*Min.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
145	12.4	7.9	23.06	1	.....	.....	(1)	½–¾	10.00	12.0	(2)	(2)	(3)	(3)
149	39.3	7.8	22.18	1	.....	.....	40	40	10.0	12.0	(2)	(2)	(3)	(3)
150	16.1	6.5	22.41	60	.....	.....	(1)	20	9.0	12.0	(2)	(2)	(3)	(3)
Average...	22.6	7.4	22.55	21	.....	.....	.....	.....	9.67	12.0	.....	.....	.....	.....

JACK PINE—HEARTWOOD.

296	17.6	7.7	24.1	30	132	88	(4)	(4)	3.10	6.60	0.80	1.20	0.10	0.10
298	12.9	8.6	25.1	60	137	90	(4)	(4)	4.0	9.6	1.60	1.60	.10	.20
297	13.9	8.6	23.9	120	150	91	(4)	(4)	6.2	8.8	1.40	1.60	.10	.10
Average...	14.8	8.3	24.4	70	140	90	.....	.....	4.43	8.33	1.26	1.47	.10	.13

BULL PINE—HEARTWOOD.

98	17.3	8.6	24.7	30	77	140	18	(4)	4.0	5.0	0.40	0.50	0.15	0.20
99	10.1	15.0	25.1	80	77	145	80	(4)	10.0	12.0	1.12	1.25	.22	.30
97	19.2	13.0	24.7	115	80	154	45	(4)	12.0	12.0	1.25	1.37	.20	.50
101	37.0	.....	25.2	17	76	148	(4)	(4)	4.40	5.60	.12	.25	.06	.10
Average...	20.9	12.2	24.9	60	77	147	.....	.....	7.6	8.7	.72	.84	.16	.28

BULL PINE—SAPWOOD.

103	13.6	21.3	27.1	15	80	150	15	(4)	3.50	12.0	0.50	1.00	1.12	0.20
104	9.6	.....	26.5	15	76	143	2	4	4.0	12.0	.22	.30	.05	.10
107	16.2	.....	29.4	15	74	140	12	(4)	6.00	12.0	.90	1.10	.35	.40
Average...	13.1	21.3	27.7	15	77	144	.....	.....	4.50	12.0	.54	.80	.17	.23

WHITE FIR—HEARTWOOD.

208	15.6	7.1	22.03	30	136	88	19	30	11.0	12.0	0.20	0.30	0.30	0.50
224	13.9	6.8	21.83	60	128	87	23	60	7.75	12.0	.20	.25	.20	.25
140	11.7	6.8	21.68	120	143	89	30	45	11.50	12.0	.20	.30	.25	.32
Average...	13.7	6.9	21.85	70	136	88	.....	.....	10.08	12.0	.20	.28	.25	.36

WHITE FIR—SAPWOOD.

162	18.3	10.7	21.84	15	129	85	15	(4)	12.0	12.0	0.30	0.60	0.50	0.90
158	8.9	8.5	23.62	60	135	87	16	26	8.00	12.0	.15	.18	.25	.37
197	9.7	7.7	23.09	120	131	88	15	60	7.00	12.0	.10	.25	.20	.43
Average...	12.3	9.0	22.85	65	132	87	.....	.....	9.00	12.0	.19	.34	.32	.57

NOBLE FIR—HEARTWOOD.

267	.....	17.8	24.7	30	129	87	10	15	8.0	12.0	0.05	0.08	0.10	0.20
279	8.7	15.0	22.6	60	145	90	(4)	(4)	4.5	7.5	.10	.20	.15	.30
276A	.....	14.1	.....	105	137	90	18	25	5.0	12.0	.20	.30	.20	.25
Average...	8.7	15.6	23.6	65	137	89	.....	.....	5.8	10.5	.12	.20	.15	.25

[1] Radially.
[2] Complete.
[3] Could not be determined.
[4] Creosote did not penetrate to end of specimens.

TABLE 4.—*Results of penetrance tests on individual pieces*—Continued.

NOBLE FIR—SAPWOOD.

Piece No.	Moisture.	Average number of rings per inch.	Oven-dry weight per cubic foot.	Total time of treatment.	Average temperature.	Average pressure per square inch.	Time required to penetrate 12 inches.		Penetrations.					
									Longitudinal.		Radial.		Tangential.	
							First end.	Second end.	Average.	Maximum.	Average.	Maximum.	Average.	Maximum.
	Perct.		*Lbs.*	*Min.*	*°F.*	*Lbs.*	*Min.*	*Min.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
272	10.8	27.3	22.2	30	144	90	5½	12	10.0	12.0	0.30	0.40	0.10	0.15
276	8.9	19.1	25.4	60	142	90	1	15	9.0	12.0	.10	.10	.30	.50
266	13.6	29.5	23.4	120	140	89	3	15	12.0	12.0	.15	.15	.90	.90
Average...	11.1	25.3	23.7	70	142	90	.....	.....	10.3	12.0	.18	.22	.43	.52

DOUGLAS FIR—HEARTWOOD.

110	12.9	13.9	28.3	30	137	88	(1)	(1)	0.30	5.0	0.03	0.08	0.04	0.09
111	7.5	12.2	27.0	60	138	88	(1)	(1)	.60	12.0	.05	.12	.05	.09
108	10.9	15.0	28.0	120	142	88	(1)	(1)	.80	9.0	.08	.10	.08	.10
Average...	10.4	13.7	27.8	70	139	88	.....	.....	.57	8.6	.05	.10	.06	.09

DOUGLAS FIR—SAPWOOD.

112	15.4	21.4	26.9	30	139	86	25	(1)	5.10	12.0	0.40	1.00	0.05	0.10
113	10.9	26.0	26.5	60	136	87	15	45	5.20	12.0	.40	1.00	.05	.10
115	15.3	21.7	27.3	120	141	87	(1)	(1)	8.00	12.0	.50	1.00	.07	.12
Average...	13.9	23.0	26.9	70	139	87	.....	.....	6.10	12.0	.43	1.00	.06	.11

SITKA SPRUCE—HEARTWOOD.

220	14.5	9.3	17.47	30	144	84	30 $\frac{1}{3\,0}$	30 $\frac{1}{3\,0}$	12.0	12.0	0.08	0.12	0.08	0.20
209	13.8	4.1	15.85	60	147	85			12.0	12.0	.10	.15	.06	.15
219	9.5	8.6	17.86	120	140	84	15	15	12.0	12.0	.10	.20	.20	.20
Average...	12.6	7.3	17.06	70	144	84	.....	.....	12.0	12.0	.09	.16	.11	.17

SITKA SPRUCE—SAPWOOD.

212	.....	11.4	18.86	.....	.....	.....	Instantly.		4.0	12.0	0.08	0.20	0.15	0.25
223	7.4	11.8	19.06	30	144	86	12	14	12.0	12.0	.10	.20	.12	.20
228	11.3	12.3	18.60	60	144	87	15	15	12.0	12.0	.10	.14	.18	.25
Average...	9.3	11.8	18.84	45	144	86.5	.....	.....	9.3	12.0	.09	.18	.15	.22

WHITE SPRUCE—HEARTWOOD.

285	10.3	10.9	24.7	30	150	85	(1)	(1)	3.30	8.30	0.05	0.10	0.05	0.15
289	14.7	18.2	22.6	60	146	86	(1)	(1)	2.00	7.50	.06	.08	.05	.10
290	9.5	10.0	23.9	120	146	86	(1)	(1)	4.50	8.75	.15	.20	.15	.20
Average...	11.5	13.0	23.7	70	147	86	.....	.....	3.27	8.18	.09	.13	.08	.15

WESTERN YELLOW PINE—HEARTWOOD.

187	12.0	8.2	23.93	30	145	87	(1)	(1)	5.25	6.30	1.25	1.25	0.05	0.10
245	.....	10.5	24.81	60	143	87	(1)	(1)	6.50	8.00	(2)	1.30	.....	.05
200	13.6	8.6	23.81	120	139	85	(1)	(1)	1.50	2.20	1.20	1.80	.....	.....
Average...	12.8	9.1	24.18	70	142	86	.....	.....	4.42	5.50	1.23	1.45	.....	.....

[1] Creosote did not penetrate to end of specimens. [2] Complete.

TABLE 4.—*Results of penetrance tests on individual pieces*—Continued.

WESTERN YELLOW PINE—SAPWOOD.

Piece No.	Moisture.	Average number of rings per inch.	Oven-dry weight per cubic foot.	Total time of treatment.	Average temperature.	Average pressure per square inch.	Time required to penetrate 12 inches.		Penetrations.					
									Longitudinal.		Radial.		Tangential.	
							First end.	Second end.	Average.	Maximum.	Average.	Maximum.	Average.	Maximum.
	Per ct.		*Lbs.*	*Min.*	*° F.*	*Lbs.*	*Min.*	*Min.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
156	10.2	16.4	23.60	1	138	88	1/3	1/3	12	12	(1)	1.00	0.22	0.20
142	21.2	15.4	22.25	2	130	88	1/6	1/4	12	12	(1)	1.00	.25	.3
238	9.1	16.8	23.82	1	126	88	5/12	.....	12	12	(1)	1.00	.....	.....
Average...	13.5	16.2	23.22	1	131	88	.....	.....	12	12	1.00	1.00	.24	.29

SPRUCE PINE—HEARTWOOD.

231	12.3	3.4	33.24	30	137	86	(2)	(2)	2.00	3.50	0.30	0.40	0.10	0.10
186	9.4	3.7	32.78	60	138	88	(2)	(2)	1.45	2.60	.30	.95	.10	.15
206	11.4	3.6	32.16	120	133	87	(2)	(2)	1.50	3.10	.30	.70	.10	.10
240[1]	13.0	4.3	29.78	3	.....	89	(3)	(3)	(1)	(1)	(1)	(1)	.....	.....
225[1]	.....	.....	30.50	3	.....	85	(3)	(3)	(1)	(1)	(1)	(1)	.....	.....
Average...	11.5	3.6	32.73	70	136	87	.....	.....	1.65	3.07	.30	.68	.10	.12

SPRUCE PINE—SAPWOOD.

144	10.5	7.7	25.48	2	130	87	2	2	(1)	(1)	(1)	(1)	.....	.....
164	15.2	8.2	25.01	2	114	89	2	2	(1)	(1)	(1)	(1)	.....	.....
141	13.0	8.6	23.33	15	120	87	11	13	(1)	(1)	(1)	(1)	.....	.....
Average...	12.9	8.2	24.61	6	121	88	.....	.....	.....	.....	.....	.....	.....	.....

LONGLEAF PINE—HEARTWOOD.

248	10.4	9.3	35.05	30	143	86	(2)	10	8.0	12.0	0.25	0.45	0.10	0.10
135	7.2	17.1	35.04	60	133	82	(2)	25	10.50	12.0	.40	.55	.10	.10
242	1.9	10.0	39.31	120	141	80	(2)	12	11.0	12.0	.50	.70	.10	.10
Average...	12.2	12.1	36.47	70	139	83	.....	.....	9.83	12.0	.38	.57	.10	.10

LONGLEAF PINE—SAPWOOD.

143	18.5	20.5	22.48	3/4	130	83	(2)	(2)	(1)	(1)	(1)	(1)	(1)	(1)
136	17.4	26.4	22.03	3/4	120	83	3/4	(2)	(1)	(1)	(1)	(1)	(1)	(1)
202	17.7	25.5	22.27	1	125	83	(2)	(2)	(1)	(1)	(1)	(1)	(1)	(1)
Average...	17.9	24.1	22.26	5/6	125	83	.....	.....	.....	.....	.....	.....	.....	.....

SHORTLEAF PINE—HEARTWOOD.

181	6.2	15.4	39.77	30	137	86	(2)	(2)	2.00	3.00	0.30	0.50	0.05	0.05
153	11.5	14.1	36.87	60	133	88	(2)	(2)	2.50	4.50	.30	.60	.05	.10
230	8.77	16.8	40.12	120	148	89	(2)	(2)	3.75	5.50	.45	.60	.05	.05
Average...	8.8	15.4	38.92	70	139	88	.....	.....	2.75	4.33	.35	.57	.05	.07

[1] Complete. [2] Creosote did not penetrate to end of specimens. [3] Not taken.

TABLE 4.—*Results of penetrance tests on individual pieces*—Continued.

SHORTLEAF PINE—SAPWOOD.

Piece No.	Moisture.	Average number of rings per inch.	Oven-dry weight per cubic foot.	Total time of treatment.	Average temperature.	Average pressure per square inch.	Time required to penetrate 12 inches.		Penetrations.					
									Longitudinal.		Radial.		Tangential.	
							First end.	Second end.	Average.	Maximum.	Average.	Maximum.	Average.	Maximum.
	Per ct.		*Lbs.*	*Min.*	*° F.*	*Lbs.*	*Min.*	*Min.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*	*Ins.*
207	12.3	13.6	31.96	1	154	88	(1)	(1)	(2)	(2)	(2)	(2)	.....	.....
203	14.6	13.5	30.10	2½	150	88	(1)	(1)	(2)	(2)	(2)	(2)	0.35	0.50
132	11.1	16.1	32.18	2½	146	86	1/12	1/6	(2)	(2)	(2)	(2)	.05	.10
Average...	12.7	14.4	31.41	2	150	87	.....	.....	.....	.....	.....	.....	.20	.30

LOBLOLLY PINE—HEARTWOOD.

213	9.7	3.5	32.49	1	132	87	(1)	(1)	2.50	8.50	.20 .90	0.50 1.80	0.05	0.05
246	9.1	2.8	33.24	60	136	88	¾	(1)	(2)	(2)	.50 1.00	1.00 1.90	.20	.20
185	12.1	4.1	31.98	120	137	88	3	5	(2)	(2)	.75	1.00 1.50	.20	.20
Average...	10.3	3.5	32.57	60	135	88	.....	.....	.....	.....	.35 .88	.83 1.73	.15	.15

LOBLOLLY PINE—SAPWOOD.

241	7.9	8.7	30.15	1/32	130	87	(1)	(1)	(2)	(2)	(2)	(2)	0.50	1.00
299	7.5	7.7	34.0	1/32	136	87	⅔	⅔	(2)	(2)	(2)	(2)	.25	.30
300	10.0	7.8	33.2	½	141	87	(1)	(1)	(2)	(2)	(2)	(2)	1.00	.50 1.50
Average...	8.5	8.1	32.45	30	136	87	.....	.....	.....	.....	.....	.....	.58	.82

[1] Creosote did not penetrate to end of specimens. [2] Complete.

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